MINIMIZING THE RISKS OF DIMINISHING MANUFACTURING SOURCES AND
MATERIAL SHORTAGES: EVALUATING ELECTRONIC AVIONICS
LIFECYCLE SUSTAINMENT STRATEGIES

GRADUATE RESEARCH PROJECT

Kenneth D. Underwood, Major, USAF

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DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY

AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

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Kenneth D. Underwood,
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Abstract

The Air Force faces increasingly difficult challenges to maintain and sustain its highly technical weapon systems, struggling against rapid technology advancement and diminishing lifecycle for electronic systems. The reduced lifecycle times have not only complicated sustainment, the lifecycles have diminished to the point that new military aircraft designs face challenges of obsolescence within the manufacturing cycle, and in some cases before manufacturing even begins. This research project explores Diminishing Manufacturing Sources and Material Shortages (DMSMS) and obsolescence cost associated with electronic avionic components. The overall research question asks how obsolescence management can be improved in the Air Force.

This project utilizes two integrated models, the first, to determine electronic avionics demand requirements for a fleet of 96 aircraft over a 30-year period, and the second to evaluate sustainment cost over time for a) re-engineering strategy, b) lifetime buy strategy, and c) programmed redesign strategy. Statistical analysis and long-term cost comparison of these three strategies will provide a framework to evaluate specific weapon systems for future studies and to develop an attainable low-cost sustainment strategy.

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LIFECYCLE SUSTAINMENT STRATEGIES

I. Introduction

Statement of Problem

The problem addressed by this research project is how to predict and proactively

respond to emerging obsolescence and Diminishing Manufacturing Sources and Material

Shortages (DMSMS) in the F-22 and other USAF weapon systems. This study examines

the obsolescence trend of micro-processors and semi-conductors used extensively in

avionic components. By analyzing current DoD and civilian manufacturing DMSMS

initiatives in relation to the current obsolescence trends, this project proposes a new

proactive approach to prevent DMSMS related supply chain disruptions for the F-22,

F-35, and other DoD weapon systems.

DMSMS, according to the *Diminishing Manufacturing Sources and Material*

Shortages Guidebook, is "the loss or impending loss of manufacturing suppliers of items

or raw materials" (DSPO, 2009). The critical DMSMS issue facing the DoD today is the

rapid obsolescence of microchips, semi-conductors, and integrated circuits used

throughout DoD electronics components. While the DoD has increased its dependency on electronic equipment across the spectrum of warfare since the 1970s, the exponentially expanding commercial electronics market has dwarfed the military demand for electronics. Consequently, chip manufacturers producing military specific microchips struggled to earn profits from the government contracts and refused to renew contracts for unprofitable production requirements, preferring to focus on chip production for the commercial sector. As a result, by the 1990s, military engineers and acquisition specialists were forced to utilize many Commercial-off-the-Shelf (COTS) electronic products and components.

COTS, however, was not a long term solution for military equipment due to the persistently decreasing lifecycle of COTS chips. Military leaders required equipment for the aging B-52, KC-135, F-15 and F-16 weapons systems as well as the new CV-22, F-22, and F-35 weapon systems. In response to decreasing military budgets and increasing military operations, the lifecycle of older weapon systems were being extended beyond fifty years in the case of the B-52 and KC-135, these leaders desired supporting electronic avionics with similarly extended lifecycles. The reliance on COTS electronics and the current rate of microchip obsolescence, with an estimated 3 percent of chips world-wide becoming obsolete every four months (Sandborn, 2007), has left engineers, acquisitions specialists, and logisticians to solve a problem where existing products do not meet leadership requirements.

Background

       Procurement of the F-22 Raptor began in 1999 with initial USAF requirements as

high as 648 aircraft to maintain an adequate Air Superiority posture to fight and win two

simultaneous major theater wars in the pre-9-11 global environment (Gertler, 2009).

After the tragic terrorist attack on September 11, 2001, US National Security objectives

and National Defense strategy have shifted as the nation went into full-scale war

combating international threats to US interests in Afghanistan and Iraq, resulting in

reduced projections for F-22 requirements due to evolving war-fighting strategies and

dwindling defense budgets. In addition to the ongoing war in the Middle East,

international support for the F-35 Joint Strike Fighter further dwindled demand for the

superior F-22 Raptor. By 2009, the number of F-22s approved for acquisition for the

USAF had been reduced to 183 aircraft, providing enough Raptors for three fighter wings

in a structured 20 wing Air Force (13 active; 7 Reserve/National Guard) (Gertler, 2009).

       With the delivery of the last F-22 scheduled for 2012, many of the over 1,000

manufacturing lines supporting the F-22 are shutting down requiring tens of thousands of

F-22 experienced workers to move to new production lines and in many cases to new

firms all together. Gertler projects that production lines manufacturing parts and

assemblies used early in the F-22 production line will shut down F-22 parts production

well in advance of the delivery of the final aircraft to the USAF, such as the F-119

engines, which are delivered eleven months prior to aircraft completion. It is estimated

that only 11 percent of the F-22 suppliers are contributing to the F-35 production, due to

significant multi-national participation, resulting in the closure of nearly 900 suppliers

supporting the F-22 supply chain creating a substantial risk of DMSMS for the F-22

weapon system (Gertler, 2009).

The F-22 is not the only weapon system in the DoD with DMSMS threats. In a

Directive Memo dated 25 March 2010, the Deputy Secretary of Defense reinforced the

importance of ensuring absolute vigilance in detecting and preventing supply chain risks.

The memo required the following:

- Supply chain risk shall be addressed early and across the entire
  system lifecycle through a defense-in-breadth approach to
  managing the risks to the integrity of information and
  communications technology within covered systems.
- Supply chain risk management capability shall be
  incrementally instituted using the pilot process shall include:
    - Incorporation of all-source intelligence analysis into
      assessments of the supply chain for covered systems.
    - Processes to assess threats from potential suppliers
      providing critical information and communications
      technologies components to covered systems.
    - Processes to control the quality, configuration, and
      security of software, hardware, and systems throughout
      their lifecycles, including components or
      subcomponents from secondary sources.
    - Processes to detect the occurrence, reduce the
      likelihood of occurrence, and mitigate the consequences
      of products containing counterfeit components or
      malicious functions (DTM-09-016, 2010).

In addition to the direction provided by the Deputy Security of Defense, the F-22

program office has received additional guidance to develop a predictive model that can

anticipate DMSMS risks and vulnerabilities.

The DoD's high operations tempo around the globe since the terrorist attacks

against the US in 2001, has resulted in increased utilization of nearly all weapons systems

with rising maintenance activities due to the acceleration of hours operated, reducing the

volume of spare parts in the DoD pipeline as well as those available from commercial

sources. In addition to reduced availability of existing parts and delayed pipeline times, many existing aircraft have already exceeded their projected lifecycle age through expensive modifications and extensive maintenance activities designed to prepare older platforms to meet new mission requirements; while cheaper than procuring new airframes, these budget expenses continue to rise year after year. Most of these modifications involve the addition of new electronic avionics integrating the older aircraft into the United States' modern warfare apparatus, driven extensively via satellite communication and rapid data delivery throughout the battlespace.

Maintaining older aircraft for decades beyond their intended lifecycle increases demands on the DoD Supply Chain, internally and externally. Internally, maintenance requirements continue to increase as the airframe gets older; externally, demands on suppliers increase, many times for components that become increasingly unprofitable for commercial companies to produce. While the F-22 is new weapon system, the disintegration of the majority of its manufacturing base as its production nears completion has caused concern in Congress and the DoD in regard to sustainability and probable DMSMS issues.

Supply chain disruptions due to DMSMS can result in catastrophic failure for the DoD as weapon systems become unsustainable. In response to DMSMS issues, the DoD often implements reactively: re-engineering weapon systems to replace the obsolete component with an available alternative, stockpiling at risk components, and contracting new companies to manufacture the item(s) (Weiss, 1995; Josias, et al., 2004; Frank and Morgan, 2007; Trenchard, 2003). While these initiatives have been successful, they are very expensive. Many scholars and researchers have pushed for more proactive

strategies to combat obsolescence (Electronics Weekly, 2002; Meyer et.al., 2004; Howard, 2002; Condra, 1999; Torresen and Lovland, 2007; Marion, 2001; Sandborn, et. at., 2005; Francis, 2006; Leonard, et al., 1988; Flaherty, 2005).

While DMSMS can affect any component type for any weapon system in the DoD, the majority of cases arise from semi-conductors and micro-processors. The development of a proactive framework to detect and counteract component obsolescence will better enable DoD leaders to meet the directive of the Deputy Secretary of Defense by reducing supply chain disruption risks and reducing the recovery costs associated with DMSMS.

Importance of Problem

The F-22 avionics systems began experiencing DMSMS shortages as early as 1997 due to the increasing rate of technology maturation. The rapid advancements made in electronics since the 1970s has changed the traditional demand process for high-tech electronics. The requirement to modernize avionics systems are now driven by the electronics market, not the military. While military requirements for modern electronics have grown at an exponential pace, the military's percentage of the microelectronics market has shrunk from 17 percent in 1975 to less than 1 percent in 1995 (Bell, 1998). At the same time microelectronics maintained consistent advances, doubling transistor capacity, processor speeds and data capacity every 24-36 months, as predicted by Gordon Moore in 1965, commonly described as Moore's Law (Moore, 1965).

In the case of the F-22, within three years of initial development several key suppliers stopped producing components required for the avionics systems, most notably

Intel's I-960 chips. While Intel and the others had committed to long term plans in the

1980s, by the 1990s new technology had eliminated the 25-Megahertz I-960 processor

with 200- and 300-Megahertz processors widely used as the new standard. Intel could

not afford to continue production of the obsolete I-960 in the small amounts required by

the F-22 program (Bowers, 2001).

Table 1. USAF Microchip Use (Hicks et al., 2003)

Processor	Year of Introduction	Transistors
4004	1971	2,250
8008	1972	2,500
8080	1974	5,000
8086	1978	29,000
286	1982	120,000
386^{TM} processor	1985	275,000
486^{TM} DX processor	1989	1,180,000
Pentium$^{®}$ processor	1993	3,100,000
Pentium II processor	1997	7,500,000
Pentium III processor	1999	24,000,000
Pentium 4 processor	2000	42,000,000

In March 2010, the Deputy Secretary of Defense issued a memo directing military

departments to improve the integrity of components used in DoD systems, to reduce

supply chain risks, and identify risks across the entire lifecycle as early as possible for all

DoD systems (DTM-09-016, 2010). Additionally, the F-22 program office has

prioritized the development of proactive DMSMS strategies to reduce these threats in the

supply chain. Costs associated with obsolescence are unavoidable; however, developing

a proactive plan for predicted DMSMS issues is much less expensive than reacting to an

unexpected obsolescence event (Bumbalough, 1999; Josias et al., 2004; Frank and

Morgan, 2007; Trenchard, 2003).

The Defense Supply Center, Columbus (DSCC) manages over 2.2 million spare

parts for the DoD with an average of 10,000 parts becoming obsolete each year. In 2003,

a total of 84 percent of all obsolete parts were electronic components and in 2005 more than 150,000 integrated circuits were declared obsolete (Kumar and Saranga, 2008). The DMSMS Guidebook describes numerous DMSMS resolution options with expected non-recurring engineering costs to implement each option and the time required to resolve the issue (DSPO, 2009). The goal of the DMSMS program is to better predict obsolescence occurrences to reduce the excessive costs associated with and remanufacturing that is often required when there is no warning or insufficient warning of a loss of supply (Howard, 2002; Feng et al., 2007).

Scope and Overall Research Question

The scope of research to develop a predictive model to forecast DMSMS is outside the time and scope of this study. Instead, this study will analyze and integrate several obsolescence forecasting models and DMSMS initiatives to build a comprehensive proactive upgrade strategy to reduce DMSMS, and improve sustainability for the F-22 and other DoD weapons systems at risk of DMSMS. This study will solely focus on micro-chips, semi-conductors, and micro-processors in an effort to model the largest percentage of DMSMS occurrences in the DoD. While the process developed in this study may be applicable to other components at risk of DMSMS, these components will not be tested in this study and will require separate tests and evaluations.

Two models will be used to compare current USAF sustainment practices in relation to a revised sustainment strategy. The first component failure rate model used in this study, named the Legacy Model, simulates current USAF sustainment processes for electronic avionic components. The Legacy Model calculates component failure in

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relation to flight hours used and the overall age of the component technology; the probability of failure increasing as hours used and overall age increases. This model accounts for repairs at the base and depot levels for the entire 30-year lifecycle of the supported weapon system. Once a component is identified for repair, the flight hours used is reset to zero, though the overall age of the technology continues to accumulate, in effect increasing the probability of failure as the technology ages. The model calculates the repair costs for each component, dependent on age of technology, to determine annual costs for the fleet, total lifecycle costs for each aircraft, and total lifecycle costs for the fleet.[1]

The second model, the Programmed Upgrade Model, simulates a revised sustainment strategy introducing technology upgrades at scheduled time intervals within the 30-year lifecycle of the supported weapon system. This model calculates component failure just as the previous model. When a component is identified for base and depot level repair, the flight hours used is reset to zero and the overall age of the technology continues to accumulate. When a component is identified for the programmed upgrade, both the flight hours used and overall age of technology are reset to zero. The model calculates repair and upgrade costs to determine annual and total lifecycle cost for each aircraft and the total fleet.

While it is expected for both models to experience increased failure rates over time, this study proposes that the Programmed Upgrade Model will experience lower

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[1] The models use the following rules to calculate demand requirements and repair/replacement costs following principles generally agreed upon in obsolescence literature: The probability of part failure increases as the number of operating hours increases; the probability of failure increases as the total age of the technology increases; the repair costs increase as the total age of the technology increases (Marion, 2001; Luke et al., 1999; Pope et al., 1998; Howard, 2002).

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overall failure rates for the 30-year weapon system lifecycle. Additionally, the overall

failure rate variance for Programmed Upgrade Model is expected to be lower than the

Legacy Model, providing opportunities to improve resource forecasting and reduce safety

stock inventories across the USAF base and depot level repair facilities. Finally, the

Programmed Upgrade Model is expected to have significantly lower lifecycle costs than

the Legacy Model.

The overall research questions for this study are:

- Is there a statistically significant difference of the component mean failure rate between the Legacy Model for and the Programmed Upgrade Model?

- Is the lifecycle variance for the Programmed Upgrade Model less than the Legacy Model?

- Is the lifecycle component sustainment cost using the Programmed Upgrade Model less than the Legacy Model?

The next chapter provides a literature review necessary to develop a specific

research methodology and data collection system for this project.   A summary of the

DMSMS and obsolescence literature provides the cornerstones for this project.

Additional material includes a detailed review of electronics and avionics obsolescence,

the transformation of the electronic lifecycle, and a discussion of the various

obsolescence forecasting models.

II. Literature Review

Purpose

This chapter analyzes the current DMSMS literature in addition to issues of electronics and avionics obsolescence, and models to predict obsolescence. Through the analysis of DoD policies and civilian strategies to prevent obsolescence impacts in conjunction with various prediction and prevention models this chapter will establish the scholarly base for the research methodology. Evaluation of various modeling approaches will assist in the development of a model to determine the best future strategies to combat DMSMS proactively for the USAF and DoD.

DMSMS

Diminishing Material Supplies and Material Shortages is the loss or impending loss of manufacturing suppliers of a product, and/or its components or parts, to include shortages of raw materials to produce items required to support a DoD weapon system (Overstreet, 2002; Meyer et al., 2004; Singh et al., 2002; Pecht and Das, 2000; Sandborn, 2007; Solomon et al., 2000; Feldman and Sandborn, 2007). While the majority of DMSMS cases involve electronic parts, primarily integrated micro circuits, and conductors, DMSMS can and does impact all Federal Stock Classes (FSC) of equipment. In the past thirty years, electronics technology has rapidly advanced resulting in shorter life spans for nearly all electronic components, with the estimates that 3 percent of global electronics become obsolete every month (Sandborn, 2007a).

DMSMS can occur at any stage of the logistics lifecycle, as early as design development or late into post-production periods (Pyett, 1997; Howard, 2002; Sandborn, 2007; Solomon et al., 2000; Singh et al., 2004; Hitt, 2000; Livingston, 2000; Josias et al., 2004; Stogdill, 1999). The potential risks for DoD weapon systems can be as minor as occasional nuisances or as severe as war stoppage. Obsolescence can greatly impact the projected logistics lifecycle costs of weapon systems, forcing the DoD to initiate new contracts to develop new sources of supply, extensive re-engineering efforts to modify weapon systems, and/or reverse engineering to develop organic manufacturing capabilities.

The Defense Standardization Program Office DMSMS Guidebook explains that the DoD is a minor consumer of electrical and electronic devices, when compared with the global commercial sector. While the electronics industry regularly abandons older low demand technology, in an effort to provide the latest and greatest advances to demanding consumers, the DoD seeks to prolong the life of its weapon systems, which have become more and more reliant on electronic technology. Scott Campbell (2009) explores the accelerating trend of obsolescence for electronics in relation to Moore's Law, describing products in the 1970s facing obsolescence within 2-3 years from production, compared to products manufactured since 2000 often face obsolescence issues in the early manufacturing phase. This conflicting trend resulted in DMSMS problems as parts and materials are eliminated by commercial firms, long before the projected end of a DoD weapon systems logistics lifecycle (Pecht and Das, 2000, Solomon et al., 2000; Singh et al., 2004; Josias et al., 2004; Sandborn, 2007; Torresen

and Lovland, 2007). Reacting to unforeseen DMSMS situations is often data intensive, complex, and expensive (DSPO, 2009).

As early as 1998, Pertowski et al. (1998) recommend the compilation of a Component Information Management System providing a data warehouse for commercial and defense companies to pool data in an effort to resolve DMSMS threats. Sandborn et al. (2005) explains that existing commercial forecasting tools provide exceptional visibility and availability of parts and components, identifying alternate suppliers when available; however, these tools are not able to predict or forecast obsolescence. The current obsolescence mitigation processes remain reactive in nature. Sandborn (2007) expands his argument for the development of a data mining algorithm to augment commercial obsolescence risks to increase the predictive capabilities of existing systems. Another approach is offered by Reed et al., suggesting the use of Value Engineering techniques to reduce the risks of DMSMS trough processes of creative thinking and design development (Reed et al., 2008).

DMSMS Management Organizations

The Government-Industry Data Exchange Program (GIDEP) is a voluntary data exchange agreement between the US government and industries in the US and Canada used to share engineering and failure data in an effort to capture and share lessons learned. GIDEP also provides critical information for contractors and engineers during the design and acquisition life cycle phase to improve reliability and reduce the total cost of ownership for many technical systems. While GIDEP began in 1959 as the Inter-Service Data Exchange Program, designed to reduce duplication of effort between the

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military services when testing and evaluating new weapon systems, the program has grown to include five major areas: Engineering Data, Failure Experience Data, Metrology Data, Production Information Data, and Reliability-Maintainability Data (GIDEP Pub 1, 2008).

In recent years GIDEP has become the system of choice for the US government and government contractors to battle the growing problem of obsolescence and material shortages. Timothy Connors (2005) provides a detailed description of GIDEPs charter, programs, and processes, highlighting the importance of implementing 'best practices' throughout the process. The GIDEP program is receives its high level policies and guidance from the Defense Standardization Executive for Systems Engineering (Richards, 1980).

While the US relies on GIDEP to manage obsolescence problem, the United Kingdom has created the Component Obsolescence Group (COG) with members from the US, Norway, Sweden, Denmark, Germany, the Netherlands, France, Spain, and Singapore and over 160 member companies. When COG was formed, its focus was semiconductors. Like GIDEP, however, the COG focus expanded quickly to include chemical devices, mechanical devices, and software (Hickey, 2004; *Electronics Weekly*, 2004). While GIDEP remains strongly focused on military technology applications, COG has a much wider scope, including rail, nuclear energy, power production, and medical technology, though 75 percent of its members are in military and aerospace.

Since the 1990s, commercial industry has also struggled with the accelerating rate of product obsolescence due to the rapid rate of technology advancement (Wilson, 2001; Gomes, 2008). Many corporations have formed internal Diminishing Manufacturing

Sources (DMS) programs to reduce the risk of undetected obsolescence threats. The

DMS programs at Texas Instruments, Honeywell Technology, Boeing, and Northrop

Grumman have strong links with GIDEP and COG, sharing DMSMS updates and alerts

(GIDEP Doc X1-C-03-142D; Porter, 1998; Schneiderman, 2010; Sullivan, 2002; Cavill,

2000). New for-hire companies, like QinetiQ, have also emerged specializing in DMS

support, offering short-term and long-term assistance (Electronics Weekly, 2002). Hard-

to-find parts brokers and after-market semiconductor manufacturers, like Lansdale

Semiconductor, Rochester Electronics, and Austin Semiconductor, provide critical

services when DMSMS issues arise (Wilson, R., 2002; Johnson, 1999; Singh et al., 2002;

Solomon et al., Frank and Morgan, 2007; Manor, 2006; Neal, 2004).

More recently, companies are beginning to offer total lifecycle assurance,

guarantees for support during the end of the products lifecycle, parts availability, and

technology transition support. In the United Kingdom, Zarlink Semiconductor has signed

an agreement with customers to support end-of life chips, providing Rochester

Electronics as a guaranteed source of supply for discontinued chips, with companies

offering similar lifecycle support emerging in the US (Cattani and Souza, 2003).

Radstone Technology implemented a program called Whole Program Life in 2000,

supporting its single-board computers and computer sub-systems (Cavill, 2000).

Additionally, many microchip manufacturing firms provide last-time buy alerts one year

ahead of production end (Provencio, 2002).

The critical DMSMS issue facing the DoD today is the rapid obsolescence of

microchips, semi-conductors, and integrated circuits used throughout DoD electronics

components. While the DoD has increased its dependency on electronic equipment

across the spectrum of warfare since the 1970s, the exponentially expanding commercial electronics market has dwarfed the military demand for electronics (Lillard, 1993; Solomon et al., 2000; Howard, 2002; Tryling, 2007; Tomczykowski, 2003). Consequently, chip manufacturers producing military specific microchips struggled to earn profits from the government contracts and refused to renew contracts for unprofitable production requirements, preferring to focus on chip production for the commercial sector. As a result, by the 1990s, military engineers and acquisition specialists were forced to utilize many Commercial-off-the-Shelf (COTS) chips.

COTS, however, was not a long term solution for military equipment because the persistently decreasing microchip lifecycle impacts COTS products at the same rate military-grade microchips. Military leaders required equipment for the aging B-52, KC-135, F-15 and F-16 weapons systems as well as the new CV-22, F-22 and F-35 weapon systems. In response to decreasing military budgets and increasing military operations, the lifecycle of older weapon systems were being extended beyond fifty years in the case of the B-52 and KC-135, these leaders desired supporting electronic avionics with similarly extended lifecycles (Sandborn, 2007; Solomon et al., 2000; Howard, 2002; Singh et al., 2004; Aley, 2006; Hitt and Schmidt, 1998; Livingston, 2000). The reliance on COTS electronics and the current rate of microchip obsolescence, with an estimated 3 percent of chips world-wide becoming obsolete every four months (Sandborn, 2007), has left engineers, acquisitions specialists, and logisticians to solve a problem where existing products do not meet leadership requirements.

Many studies have been conducted to evaluate COTS solutions for the increasing trend of obsolescence (Asher, 1999; McHale, 2001; Wilson, 1999; Redding, 1995;

Prophet, 2002; Condra, 1999; Livingston, 2000; Pope et al., 1998; Dowling, 2000, Baca, 2005). Graham Prophet (2002) explains that COTS remains a postponement mechanism for obsolescence challenges, recommending improved end-of-life forecasting and accurate cost models to determine the optimum point of replacement for electronic systems. J.R. Wilson has published several articles examining the inadequacies of using COTS as a sole strategy to prevent obsolescence (1999). His next article explored the development of the COTS-focused DoD DMSMS strategy (2000). He then addressed the importance of developing a cross-functional DMSMS strategy to include product design, engineering, and accurate lifecycle information to reduce the DoDs reliance on COTS as a standard solution (2001). In the aftermath of the terrorist attack against the US in 2001 and the deployment of US troops to Afghanistan, Wilson published another article describing the rising rates of obsolescence problems for the US military (2002).

Jim Asher (1999) argues that the effectiveness of the COTS strategy has been diminished due to the more strenuous requirements for military operations. Asher argues that the unintended result of the COTS strategy has accelerated the withdrawal of major microchip manufacturers from the military market while remaining microchip manufacturers refuse to manufacture microchips that meet the MIL-STD and MIL-SPEC requirements. While the DoD routinely turns to expensive redesign and after-market manufacturing, Asher argues that hundreds of millions of finished products using MIL-SPEC manufactured chips remain in inventory at many continuing supply manufacturers in the US. Asher recommends acquiring these MIL-SPEC microchips before implementing the more costly reverse engineering process.

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John McHale examined the US Army's gradual movement away from the COTS strategy for its Firefinder weapon system. The Army has contracted Radstone Technology to upgrade the circuit boards for the Firefinder's counter-artillery radar system. Northrop Grumman designers however, have asked Redstone to use the existing circuit boards, rather than purchase the latest generation boards, to prevent rewriting and re-qualifying the Firefinder software. Upgrading the existing circuit boards, instead of installing completely new circuit boards, reduces the overall lifecycle cost of ownership for the weapon system, while providing industry leading safeguards to prevent obsolescence (McHale, 2001; Hamilton and Chin, 2001; Cavill, 2000).

In the UK, Ministry of Defence (MoD) officials struggled to maintain its fleet of Agusta Westland/Boeing WAH-64D Apache AD-1 helicopters when scores of replacement parts disappeared from the commercial market. Working closely with the COG, the MoD negotiated with existing suppliers, after-market parts brokers, and "trailing-edge" technology manufacturers to ensure the sustainment of the Apache fleet (Jennings, 2009).

In addition to COTS, the DoD developed the Generalized Emulation of Microcircuits (GEM) program in 1988. GEM manufactures electronic circuits, conductors, and other parts that are no longer available from commercial sources. GEM supports a wide variety of weapon systems DoD-wide, though in 12 years it has only manufactured 45,000 microcircuits (Bumbalough, 1999; Robinson, 2004). Concerned about the high costs associated with after-market manufacturing, Rhea (1998) and Sandborn (2008) examine the GEM reverse engineering program, explaining that continued use of trailing edge technology increases costs from as much as 50 percent to

500 percent more than the original part. As a government organization, GEM is prohibited from competing with commercial suppliers, however if commercial suppliers cannot supply the required items, GEM has been able to manufacture many microchips at a cost lower than the previous COTS price (Rhea, 1998). While redesigning, engineering, and manufacturing obsolete microchips is extremely costly, the GEM program has ensured sustainability and availability of DoD weapon systems.

Obsolescence is not limited to the older DoD legacy-systems such as the B-52. At the current rates of technology advancement in electronics, microcircuits, and computing, the multi-year design and manufacturing time for many of the DoDs newest weapon systems increase the struggle against component obsolescence on the manufacturing line (Josias, et al., 2004). Giles Slade's book, *Made to Break* (2007), explores the rapid acceleration of obsolescence in manufacturing, highlighting industrial competition and the transformation of the US economy into a new culture where identity has become extrinsically linked to spending. While Slade's book does not focus on military technology, it does provide an excellent portrayal of the changes in US culture and manufacturing during the historical period from 1975 to 2005, highlighting the increased commercial demand for electronics, shrinking the DoD requirements from 19 percent of the total microcircuit market in 1975, to less than 0.5 percent in 2005.

Lifecycle Changes

The lifecycle of an item is commonly defined as the period of time "from cradle to grave" of an item, to include design, manufacturing, customer use, and disposal (Zuashkiani, 2010). Many authors of obsolescence research agree that electronic

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subcomponents have shorter lifecycles that the products which they support, increasing

obsolescence rates throughout the electronics industry (Pecht and Das, 2000; Feldman

and Sandborn, 2007; Condra, 1999; Feng et al., 2007; Meyer et al., 2004; Craig, 2002;

Mont, 2004). Optimizing a lifecycle is often determined by the primary user of the item

based on total lifecycle costs, total lifecycle benefits, or other user specific requirements

that may determine the usefulness of the product. In the commercial sector, electronic

product lifecycles are eroding from 3-5 years in the 1980s, to less than 18-24 months in

many cases, due to rapid advances in microchip technology and the increasingly

competitive electronics market. From 2003 to 2006, integrated circuit density increased

ten-fold, while requirements to combine digital and analog circuitry on the same chips

further increased chip design complexity (Kareem and Singh, 2006).

Product Life Cycle Model

	Stage 1 Introduction	Stage 2 Growth	Stage 3 Maturity	Stage 4 Saturation	Stage 5 Decline	Stage 6 Phase-Out
Sales	Slow increase	Increasing rapidly	Stable	Leveling out	Decreasing	Lifetime buys offered
Price	Highest	Declining	Stable	Stable	Rising	High
Usage	Low	Increasing	Stable	Stable	Decreasing	Decreasing
Part Modification	Frequent	Major	Periodic changes	Few	Few or none	None
Competitors	Few	High	Stable number	Decline begins	Declining	Declining
Manufacturer Profit	Low	Increasing	Stable	Stable	Reasonable for survivors	Reasonable for survivors (aftermarket)

[i] A Sector of The Electronic Industries Alliance

Figure 1. Product Life Cycle Model (Livingston, 2001)
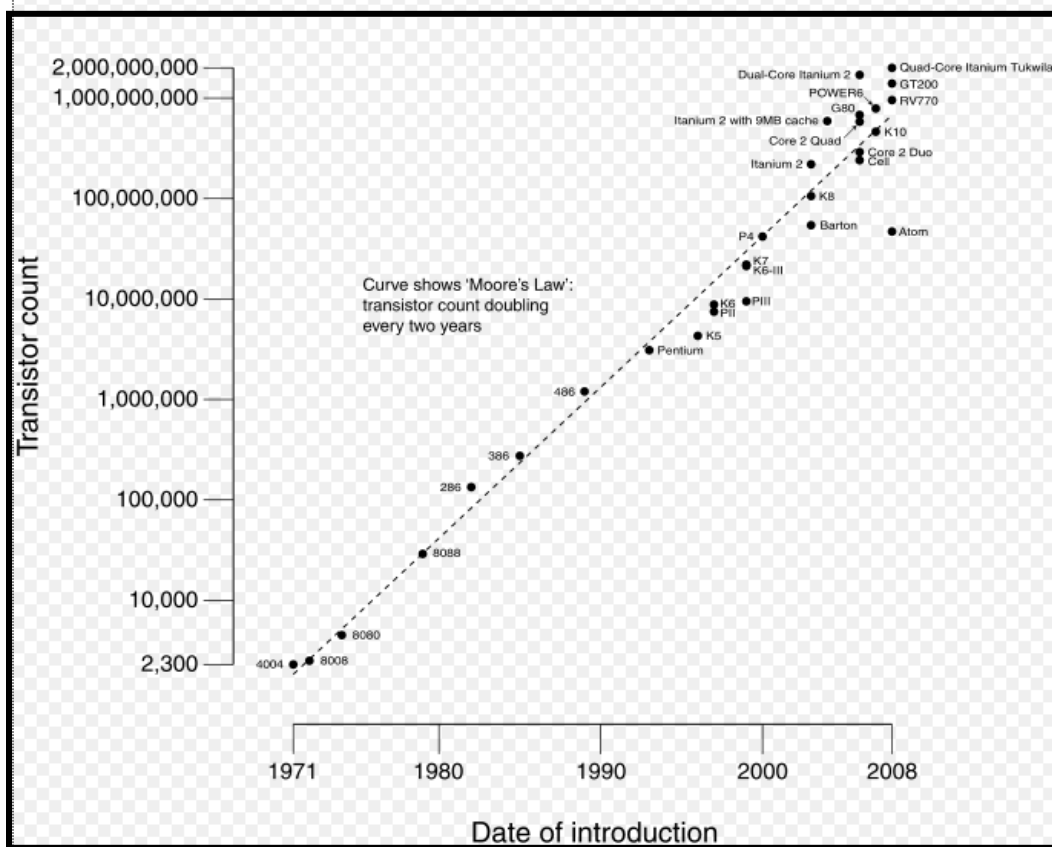
Figure 2. CPU Transistor Counts 1971-2008 & Moore's Law (Moore, 2011)

While microchip manufacturers struggle to design and manufacture state-of-the-art chips for the competitive commercial electronics market, the DoD remains focused on developing long-term sustainable electronics components to compliment its arsenal of multi-million dollar weapon systems, with lifecycle designs to span thirty years or beyond. Consumer expectations that end-item components and repair parts will be available for the total lifecycle of the product, have become nearly unattainable. DeSantis (2004) urges consumers to analyze the rate of technology advances, include technology upgrade requirements in planning and total lifecycle projections, and communicate with the manufacturers to align technology expectations with current and forecasted microchip capabilities.

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In most cases the DoD determines lifecycle parameters for weapon systems and other equipment through forecasted lifecycle cost models, planning sustainment, renovation, and acquisition budgets in relation to the 5-year DoD budget cycle. In most cases, the DoD purchases avionics components with an expected lifecycle of 5-10 years, exceeding the current chip lifecycle of 18-24 months. When these avionic sub-components are new, operations & maintenance (O&M) costs are relatively low, however, over time these costs increase. With the current rate of technology advancement, new products with improved performance and lower O&M costs enter the market at a rate equivalent to the average chip lifecycle, pressing the DoD sustainment agencies to determine the costs associated with sustaining components with increased obsolescence risks, or replacing the current item fleet-wide.
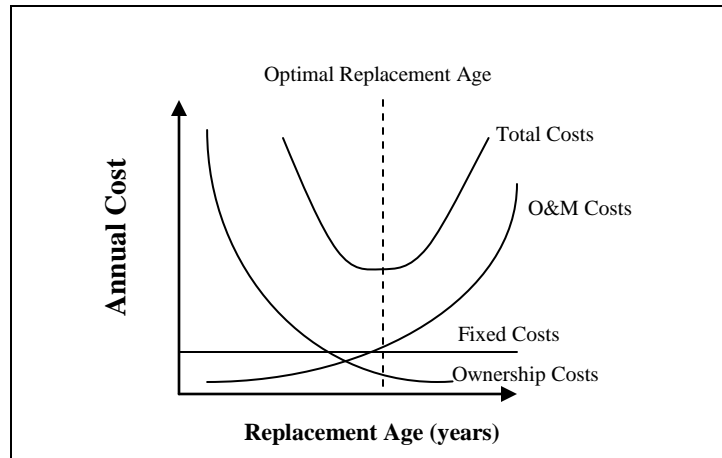
Figure 3. Avionics Optimal Replacement Age Diagram (Zaushkiani, 2010).

Total cost of ownership of an item decreases over time represented in the equation **$(P-r_1)/r_a$**, where P equals the purchase price, r_1 equals the resale cost at the time of replacement and r_a equals the replacement age. While ownership costs are reduced per unit of time, O&M costs tend to increase as the item ages (Zaushkiani, 2010). The total

cost associated of retaining an item at different points in time is a summation of total ownership cost and O&M cost over time, as seen in figure 3.

Determining the optimal point in time to replace equipment is a common practice for many vehicle and wheeled equipment items throughout the DoD. As equipment continues to age, repair costs are evaluated against a total cost matrix, evaluating the replacement cost of the item and the mission impact if not repaired to determine replacement priority. A formula to determine the optimal replacement point for equipment is $\mathbf{R_o = A + \Sigma_{1-n}M_i + D - \Sigma_{1-n}S_i}$ where R equals the equivalent annual cost associated with the replacement cost occurring over n periods; A equals the acquisition cost of the replacement item; M equals the O&M costs during each period, i=1,2,…,n; D equals the disposal cost; and S equals the resale value of the item at each period, i=1,2,…,n (Zaushkiani, 2010).

Mary Kasarda et al. (2007) recommend implementing a new concept of "design for adaptability" (DFAD). They suggest that products are retired from the market primarily because it was not adaptable. During the product design and engineering phases, adaptability should be integrated into the design, allowing for product upgrades and changes to meet changing requirements, thereby extending the lifecycle of the product.

Obsolescence in Electronics and Avionics

The DoD and USAF have dealt with problems of obsolescence in war material throughout their history, however, the battle against obsolescence has grown exponentially since the world-wide expansion of commercial electronics and computer

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sales as early as the 1970s. Life expectancy for electronic components in the 1960s was 20-25 years. This life expectancy continued to shrink as new technology increased the speed and amount of data microchips could process, in line with growing demand for electronic products globally. By 1970 life expectancy had dropped to 15-20 years, 1980 saw further reductions to 10-15 years, 7-10 years in the 1990s and 5-7 years for microchips and semi-conductors used since 2010 (Low-Cost, 1995). Additional studies of reduced lifecycles for electronics include Brooks' 1981 AFIT thesis analyzing electronics production and design, determining a trend toward producing faster, smaller, less expensive items with wider applications and reduced energy consumption (Brooks, 1981). Next, Fisher and Sheehan's 1982 AFIT thesis described the obsolescence of vacuum tubes and transistors in the USAF (Fisher and Sheehan, 1982).

By the 1990s, most research in electronics obsolescence focused on developing models to deter the growing problem of obsolete parts in the DoD. A 1993 Rand study of reparable aircraft parts analyzed forecasting techniques recommending the revision of the AFMC ordering procedures for the majority of avionics parts (Adams et al., 1993). An executive research project from the National Defense University analyzed DMSMS of microcircuits concluding that the DoD had lost leverage against electronics manufacturers as military purchases of technology items became dwarfed by the commercial market (Pyett, 1997). An IEEE article the same year explained that the military market share in the electronics industry was "shrinking to the point of disappearance" (Condra, 1999).

The DoD has moved aggressively to curb the tide against the threat of obsolescence. The GAO delivered its report on Defense Microelectronics in 2005,

highlighting DoD facilities conducting research and production of microelectronics in response to DMSMS challenges (GAO, 2005). The Department of the Navy published their DMSMS Management Plan in 2005, and the Defense MicroElectronics Activity (DMEA) published its Acquisition Guidelines in an effort to establish a proactive obsolescence strategy during DoD contract development, which was expanded in 2008 in a report from the Institute for Defense Analysis (Dept of the Navy, 2005; DMEA, 2007; Reed et al., 2008).

More recently obsolescence research had expended from a niche academic field followed primarily by military logisticians into a mainstream academic concern with journal articles appearing with more frequency in peer reviewed logistics and acquisition journals. Henry Livingston, the vice-chairman for government electronics and information technology published a report analyzing obsolescence in a product lifecycle approach for micro-circuits, arguing that product designers and engineers must be integrated into the obsolescence struggle in order to design products that will be more adaptable when microcircuit obsolescence occurs (Livingston, 2001). Manufacturing processes for micro-chips have been the focus of several studies analyzing the impact of mergers in the chip manufacturing industry in relation to the continued trend toward shorter and shorter lifecycles for high-tech chips. Josias et al. (2004) examined component obsolescence risk factors, identifying a range of microchips and microcircuits with statistically higher risks of obsolescence within specified time intervals. These studies found that consolidation of manufacturing firms linked with spiraling entry costs to establish new manufacturing firms, has driven many manufacturers of niche markets out of business. As a result, the largest chip manufacturers continue competition to

deliver the fastest and smallest chips to the commercial market, driving the ever-shrinking lifecycles of chips (Macher, 2009; Pangburn, 2009; Gravier, 2009).

In response to the diminishing leverage of military organizations in the micro-chip market, NATO promoted the use of commercial components for avionics and other electronics in its 2001 microchip obsolescence strategy (NATO, 2001). A 1998 report from the Air Force Research laboratory supports the transition from military-specific avionics components to Commercial-off-the-Shelf (COTS) components, improving supportability, and improvements with significant cost savings, reduced risks and predictable incremental upgrades (Haldeman, 1998).

Repair Costs for Avionics

As electronic components, particularly aircraft avionics, grow older they often break in unanticipated ways requiring more frequent repairs at costs of 1.5 to 5 times the original procurement cost (Rhea, 1998; Marion, 2001; Luke et al., 1999; Pope et al., 1998; Feldman and Sandborn, 2007). McDermott et al., (1999) analyzed the financial costs required to respond and solve obsolescence issues. While McDermott's study analyzed the costs typically reported in business accounting records, Atterbury (2004) explains that many of the costs to solve incidents of obsolescence remain hidden. He explains that the cost to defuel or refuel an aircraft, additional labor hours to research alternative suppliers, revise technical orders and schematics, and revise the bill of materials are not accurately accounted in traditional business reporting.

Hitt and Zwitch (2002) identified an increased repair cost of over 300 percent for aging avionics from 1998 to 2004. Their model recommends using COTS to reduce the

engineering costs for new system development, though falls short of offering guidance

for developing sustainable architecture for future components. Brian Hicks et al. (2003)

study analyzes the USAF's 90 models, in its fleet of 5,778 aircraft, using a multitude of

avionics systems. Among these aircraft, the avionics systems have as few as 53

repairable components, and as many as 475, with a total dollar value of $42.4B and

$30.6B in spare parts, with an annual depot cost of $1.2B to maintain these parts. In

2004, the US Navy estimated its annual obsolescence mitigation costs of over $750M

(Adams, 2005).
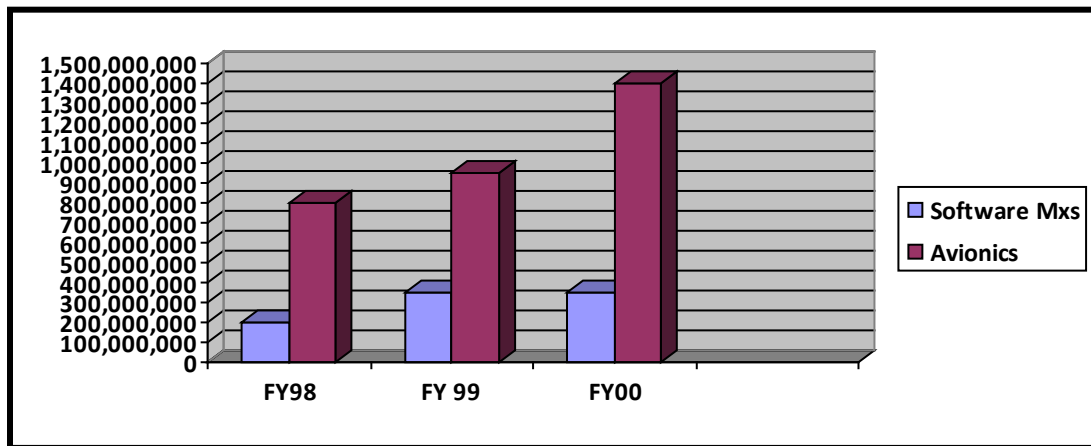
Figure 4. USAF Avionics O&M Costs (Hitt and Zwitch, 2002)
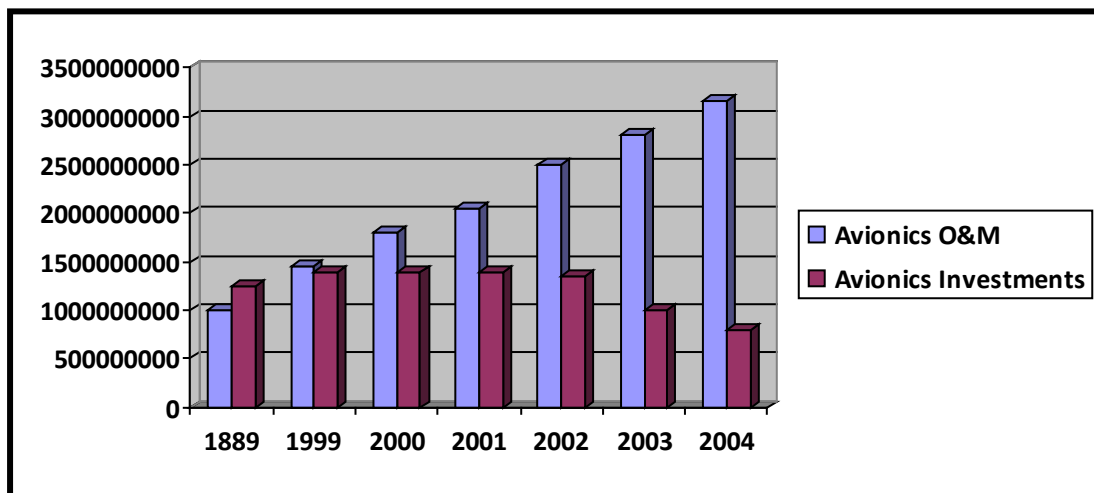
Figure 5. USAF Avionics Expenditures Forecast (Hitt and Zwitch, 2002)

While most obsolescence research have detailed the extensive costs at the USAF

or DoD levels, Bryan Steadman et al. (2000) looks at the F-16 AN/APG-68 radar system,

categorizing the 39 electronics assemblies in the system and identifying the cost drivers

in the repair process. In 1999, the annual repair cost for this radar system was $11M,

with an annual growth of 3 percent. Steadman identified 27 assemblies responsible for

the total repair costs in 1999, with 3 key components representing nearly 50 percent of

the total repair costs: memory cards ($3M), CPU RAM ($1.95M), and the power supply

($1.45M). The failure rate of the old memory cards was over 300 per year with a repair

cost of $3,600 each. Steadman recommended replacing the obsolete 32K-512K memory

card ($14,000/card) with a new 1024K card ($4,000/card), taking advantage of memory

cards readily available on the market at a much lower cost while doubling the memory

capacity. While card replacement worked in this example, many times the system

architecture prevents generic replacement of memory, processors, or transistors due to

specific design issues.

Obsolescence Models

As obsolescence problems became more frequent Nelson and Norman (1977) and

Sugata Marjit (1992) conducted studies to examine possible correlations between

production techniques and obsolescence incidents. By the 1990s, the DoD's struggle

against technology obsolescence led to an array of studies to determine obsolescence

causes and solutions, often for very specific components. In 1998 Captain John Bell

argued for improved tracking and forecasting methods to predict obsolescence for the

F-15 aircraft radar systems and other avionics components, and the expeditious

deployment of these tools Air Force-wide (Bell, 1998). Leiutenant Michael Gravier

developed a regression model to predict obsolescence of integrated circuits, determining

that the primary indicators for obsolescence were age of the design and MIL-SPEC

versus commercial specifications of the integrated circuits (Gravier, 1999). Finally, in

1999 Gary Maddux prepared a technical report for the US Army Aviation and Missile

Command outlining the urgency of the DMSMS problem for semi-conductors and

microchips. He recommended the establishment of annual DMSMS conferences between

the DoD and defense contractors, designing a simulation tool to predict DMSMS issues,

and the need for continued aggressive research to resolve issues of obsolescence

(Maddux, 1999).

While Maddux's model was helpful to predict obsolescence in the material stocks

in 1999, the use of MIL-SPEC integrated circuits had been dropping since 1994, when

then Secretary of Defense Dr. William Perry endorsed the use of commercial "parts and

practices" across the DoD. In many cases the response to the SecDef's declaration was to

virtually abandon MIL-SPEC integrated circuits, microchips and semi-conductors

(Chapman, 2004). Michael Pecht (2008) analyzed the practice of up-rating commercial

micro circuits to meet MIL-SPEC requirements, with temperature range of the chips a

primary factor for substitution.

Peter Sandborn (2007) proposed a forecasting model analyzing sales data for

electronic parts, (using the mean sales and standard deviation) plotted against the

predicted lifecycle curve for the item to predict the remaining lifecycle for the specific

part and future versions of this part. This approach uses a fixed window of obsolescence,

determined as a fixed number of standard deviations from the peak sales year.
Sandborn's model did not find a strong correlation between sales and obsolescence for flash memory chips, though the model did find a correlation between sales data and obsolescence for memory modules. This model heavily relies on continuously accurate data, with forecast data becoming more accurate as obsolescence approaches. Several authors have offered modified forecasting models, each with its own limitations and parameters (Henke and Lai, 1997; Feldman and Sandborn, 2007; Sandborn et al., 2005; Sjoberg and Harkness, 1996; Blackman and Rogowski, 2008).

An early model presented by Brown et al. (1964) explores inventory level decisions and forecasting for products threatened by obsolescence. Pertowski's (1998) obsolescence management model focused on the integration of information management systems, leading to the development of the Government-Industry Data Exchange Program. Amspaker (1999) emphasized the need to look beyond electronics, thereby including raw materials, durables, and software into the DMSMS program. Overstreet (2002) incorporated process mapping strategies utilizing the Bill of Materials (BOM) and supply chain maps.

Roland Geyer examines the economics of remanufacturing obsolete components, concluding this as a viable option if the remanufacturing location can meet demand, remanufacturing is less expensive than manufacturing new items, and remanufacturing costs keep final O&M costs below the total cost replacement level (Geyer, 2007). More recent models include product design to prevent component lifecycle mismatch, lifetime purchase decisions for items with multiple obsolete parts (Bradley, 2009; Cattani and Souza, 2003; Ellram, 1995; Pecht et al., 2002; Meyer et al., 2004; Torresen and

Lovland, 2007), and technology refreshment strategies (Singh et al., 2003). While each

of these models can be optimal in specific situations, neither is optimal for every

situation. Each model is greatly dependant on total cost/replacement cost ratio

forecasting, using these models to determine forecasted total cost over the budget period

and lifecycle of the weapon system and sub-system.

Key Issues

The DoD has struggled with DMSMS and obsolescence issues with varying

degrees of success. While DMSMS remains a critical focus item in acquisition,

engineering, and logistics, the problem is far from solved, perpetuating obsolescence

risks for DoD weapon systems. Developing a model that provides a cost-based

replacement forecast for avionics components and other electronic sub-systems for DoD

weapon systems, based on obsolescence trends for electronics, will reduce the risks of

obsolescence events crippling major weapon systems. Additionally, this model will also

provide forecasts to sustain DoD weapon systems, optimize O&M sub-system

maintenance budgets, reducing the weapon system total lifecycle cost.

<center>**III. Methodology**</center>

Introduction

   This study will analyze differences in total cost for DMSMS obsolescence of avionics components in a fleet of 96 aircraft by utilizing an Excel-based normal interval model to determine component demand over a 30-year lifecycle for the Legacy Model and the Programmed Upgrade Model. Analysis of these models will provide the framework to determine a viable sustainment strategy for electronic avionic components that will reduce total lifecycle costs for avionics, avionics sub-systems, and larger weapons system.

Methodology Issues

   While there are many factors to consider when forecasting DMSMS and obsolescence, the models used in this study limit the number of avionics components evaluated to 3, each supported through a network of microchips, semiconductors and integrated circuits, serviced as a micro-electronics sub-component during base and depot level repairs. The models are additionally limited to one aircraft type, though they can be expanded to include multiple aircraft types with unique or shared avionics components for future studies. The models simulate the 30-year weapon system lifecycle analyzing sub-system lifecycle times in relation to total cost/sustainment cost analysis. The models makes three critical assumptions: 1) immediate re-supply when a part is required; 2) every aircraft will fly its assigned missions; and 3) the Programmed Upgrade Model assumes that the design, engineering, and manufacturing of upgrade packages will

<center>32</center>

incorporate the technical details and requirements to ensure full mission capabilities of both the avionic component and the supported weapon system.

The development of a successful forecasting model for DMSMS items will have an enormous impact not only for the F-22 system, but for all future weapons systems designed for the DoD and allied nations, as well as many commercial companies. By forecasting obsolescence, the DoD will be better able to determine true lifecycle-costs for weapon systems, initiate corrective measures to prevent a suspected DMSMS occurrence, and/or develop programmed technology upgrade intervals, greatly reducing the costs and risks of DMSMS events.

Experimental Design

The models use a series of random number calculations based on a probability of failure for the electronic component in a pre-flight test and a post-flight test for each aircraft. The simulated aircraft have been given predetermined ages, representing a newly acquired weapon system delivered between April 2007 and January 2011, delivered in lots of six aircraft in the months of January, April, July, and October.[2] Each aircraft is scheduled to fly one three-hour training mission every three days. The mission length is determined by another normal interval calculator with a mean of three hours and a standard deviation of thirty minutes. The avionics use times for each mission is twice the mission flight time, capturing additional time the systems are operating during pre-flight inspections, routine maintenance, and post-flight checks. The models calculate the

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[2] See table 8, Aircraft Age at Model Start, in the appendix.

standard deviation for the probability of failure based on hours of operation and the

remaining lifecycle period of each of the avionic components. If the component fails, the

models provide a replacement and records the demand requirement for each.[3]
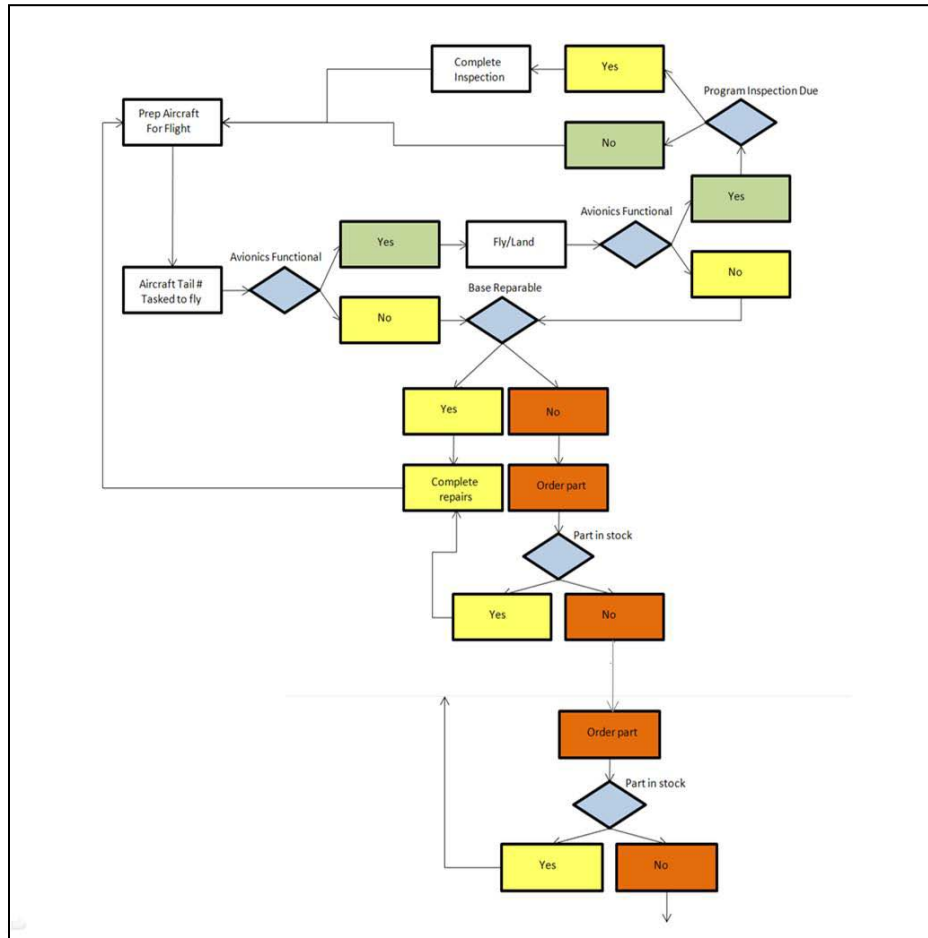
Figure 6. Avionics Failure Test Process

The average failure rate of the avionic component (R) is the leading variable for

the demand rate models.   The value of R is the average failure rate for the avionic

component. For this model, the value of R is set at 5840 hours, equivalent to three years

of operational flying. The avionics systems for each aircraft are inspected before and

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[3] See table 9, Legacy Model Avionics Demand Data, and table 10 Programmed Upgrade Model Avionics Demand, in the appendix.

after each flight to determine serviceability. The model assumes that a replacement

component is available for immediate installation, and that every aircraft will complete

its scheduled mission.

The preflight failure test was conducted by generating a normal interval random

number with the mean and standard deviation determined by the age of the component at

the time of the test. The mean value for the random number used the formula

$((\rho=L*H_i^{1/3})/2)^2$ and the standard deviation was calculated with the formula $(1-L)^{1/2}$.

The returned value was evaluated against the value of R, if $\rho<R$ then the avionic

component worked, if $\rho>R$ then the component failed. If the component failed, the

system would be rebooted by the maintenance personnel, represented in another random

number calculation (.0001 - .9999) evaluated against L_i, if the reboot value is $>L_i$, then

the system rebooted with normal operations, if the value is $<L_i$, then the system requires

repairs and a new component is issued from supply to be installed on the aircraft.

R = Average failure rate for the avionic component
A = Avionic hours operated ($A=2F$)
F = Flight hours
O = Optimal Life of the avionic component ($O=1.5*R$)
M = Maximum life of the avionic component ($M=2R$)
L = Percentage of lifecycle time remaining ($L=M-\Sigma_{1-n} A_i/M$) for each period, i=1,2
H = Hours of optimal use remaining ($H_i=O-\Sigma_{1-n} A_i$)* for each period, i=1,2
β = Optimal hours remaining coefficient ($\beta=(1-1/L_{i-1})$)
ρ = preflight failure test ($((\rho=L*H_i^{1/3})/2)^2$)
*note: When a new component is issued from supply, the Legacy Model calculates
the new component lifecycle hours of optimal use remaining is βH_{i-1}; the
Programmed Upgrade Model component lifecycle hours of optimal use remaining
is O.

Figure 7. Demand Model Definitions

Once the test was completed, the aircraft flies the mission with its total flight time

determined as a random number with a mean value of 3 hours and a standard deviation of

.5 hours. The total avionics operation time is calculated as A=2F, capturing the preflight

and post-flight tests and maintenance procedures. When the aircraft returns from its

mission the avionics systems are checked again in a post-flight check using the same

calculations, using the new additional flight hours from the most recent mission to

calculate the new values for L and H.

The time interval for the simulation is set for 30-years, evaluated in 1-day

increments from 1 Jan 2011 to 31 December 2041. The aircraft and avionics systems

history for the test population have been calculated using the acquisition date as the initial

start date for each aircraft numbered 1-96 as outlined in the appendix.[4] The model

simulates the acquisition of 24 aircraft per year, with 6 aircraft delivered each quarter—

January, April, July, and October, beginning 1 April 2007 and completed 3 Jan 2011—

and calculates flight times and supply demand requirements for the test period. Once the

aircraft history results were calculated, the model results for the 30-year test period (Jan

2011-Dec 2041) was isolated and analyzed.

The cost comparison models for the Legacy Strategy and the Programmed

Upgrade Strategy are based on repair and acquisition costs for the F-16 AN/APG-68

radar memory cards (Steadman, 2000). Both models assumed an annual repair cost

increase of 3 percent and evaluated components with initial acquisition costs of $8,000

for component A, $10,000 for component B, and $12,000 for component C. Initial repair

costs were evaluated at $1,000 for component A, $2,000 for component B, and $3,000 for

component C with programmed upgrade costs estimated at $2,000, $2,200, and $2,400.

Annual and lifecycle costs were calculated as $S_o = \Sigma_{1-n} A_i + \Sigma_{1-n} C_i$ where S equals the

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[4] See table 8, Aircraft Age at Start of Model, in appendix.

equivalent annual sustainment cost occurring over n periods; A equals the acquisition

cost of the replacement item; C equals the O&M repair costs during each period,

i=1,2,…,n. The Legacy Model assumes no new system acquisition costs relying on

repair processes to sustain the avionic components, whereas the Programmed Upgrade

Model calculates a 5-year upgrade cost in the repair process and a 15-year programmed

replacement cost. While the repair costs for the Legacy Model continue to increase by 3

percent annually, the Programmed Upgrade Model assumes that the introduction of new

technology during the upgrade and replacement model will reset the repair costs at the

original amount due to Moore's Law and the trend of new technology cost trends.

Description and Design of Specific Research Questions and Hypotheses

Analysis of obsolescence and DMSMS in electronic avionics systems leads to two

initial questions.

- Is there a statistically significant difference of the component mean failure
  rate between the Legacy Model for and the Programmed Upgrade Model?

- Is the lifecycle component sustainment cost using the Programmed Upgrade
  Model less than the Legacy Model?

The first question explores weapon system specific trends for mean failure over

time. The second question looks at the impact of a long term DMSMS strategy change

on the lifecycle sustainment cost of electronic avionic components. This cost comparison

will provide initial support for a change in the DMSMS strategy for the USAF and DoD.

A null hypothesis and test hypothesis have been provided for each of these questions.

Question 1: Is there a statistically significant difference between the Legacy Model mean failure rate and the Programmed Upgrade Model mean failure rate.

H$_{01}$: The Programmed Upgrade Model mean failure rate is not statistically different from the Legacy Model.
H$_{a1}$: The Programmed Upgrade Model mean failure rate and the Legacy Model mean failure rate are statistically significant.

Question 2: Does the Programmed Upgrade Model provide a significant lifecycle sustainment cost savings?

H$_{02}$: The Legacy Model lifecycle sustainment costs are less than or equal to the Programmed Upgrade Model lifecycle sustainment costs.
H$_{a2}$: The Programmed Upgrade Model lifecycle sustainment costs are significantly less than the Legacy Model lifecycle sustainment costs.

The model results compiled for each of the three avionic components is analyzed and compared for consistency in the model group, then against its counterpart component in the alternative model. The first hypothesis is tested by comparing mean component failure rate from the Legacy Model and Programmed Update Model using a two-tailed paired T-test. Next, the lifecycle variance for component failure is calculated for each model and compared. Finally, lifecycle sustainment cost are computed and analyzed.

IV. Analysis and Results

Context of Model Results

This section details of the comparative analysis of the Legacy Model and Planned Upgrade Model results. Two demand models have been presented and analyzed using paired-tail T-tests and a cost comparison model to evaluate annual and total lifecycle sustainment costs for the three simulated avionics components. The first model represents 96 aircraft and three avionics components using a model that assumes continuous supply with planned upgrades over the 30-year lifecycle. The second model represents 96 aircraft and three avionics components with a continuous supply that integrates technology upgrades and one replacement cycle for the components within the 30-year lifecycle of the supported weapon system.

Analysis and Findings

The Average Component Time to Failure results collected from the Legacy Model has a normal distribution as seen in the histogram charts. The results have a wide range spanning from 100 hours to 4,800 hours with an average value of 3,300 hours. While the overall distribution of the model results has normal characteristics, the distribution pattern is easier to recognize in the time interval histograms.

Figure 8. Legacy Model Component A--Lifecycle Average Time to Failure

Figure 9. Legacy Model Component A--2011-2020 Average Time to Failure
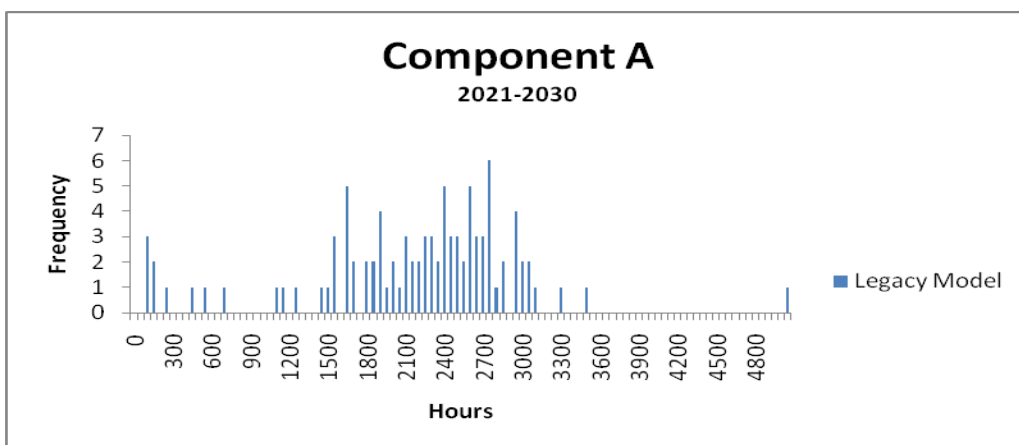
Figure 10. Legacy Model Component A--2021-2030 Average Time to Failure
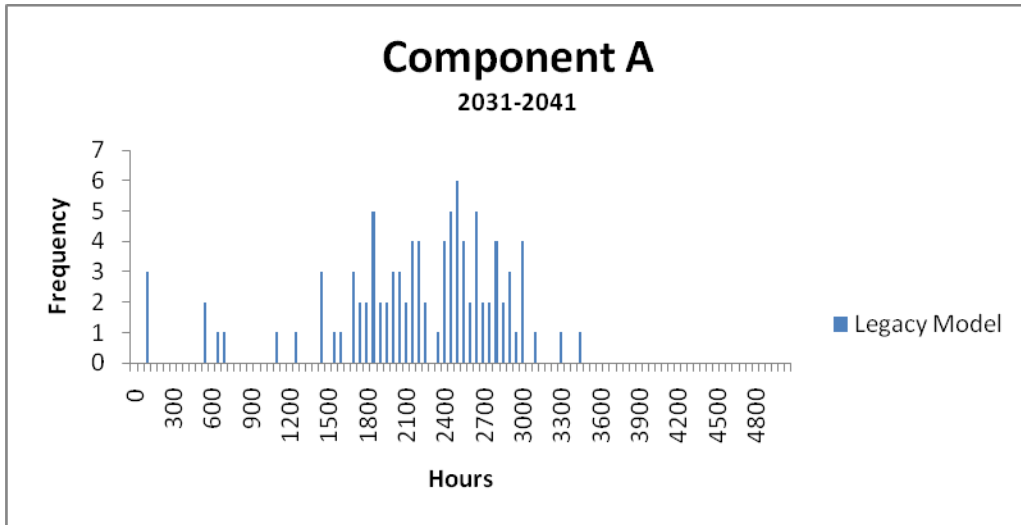
Figure 11. Legacy Model Component A--2031-2041 Average Time to Failure

Analysis of the time interval histograms indicates a reduction in the mean Time to Failure for component A, from 3,200 hours in the first interval to 2,150 hours in the second and third intervals. The component B average Time to Failure in interval 1 was 3,200 hours. During interval 2 the average fell to 1,950 hours, and in period 3 the average increased slightly to 2,150. Component C experienced similar changes with the Time to Failure in interval 1 at 3,150 hours, interval 2 at 1950 hours, and interval 3 at 2,150 hours.
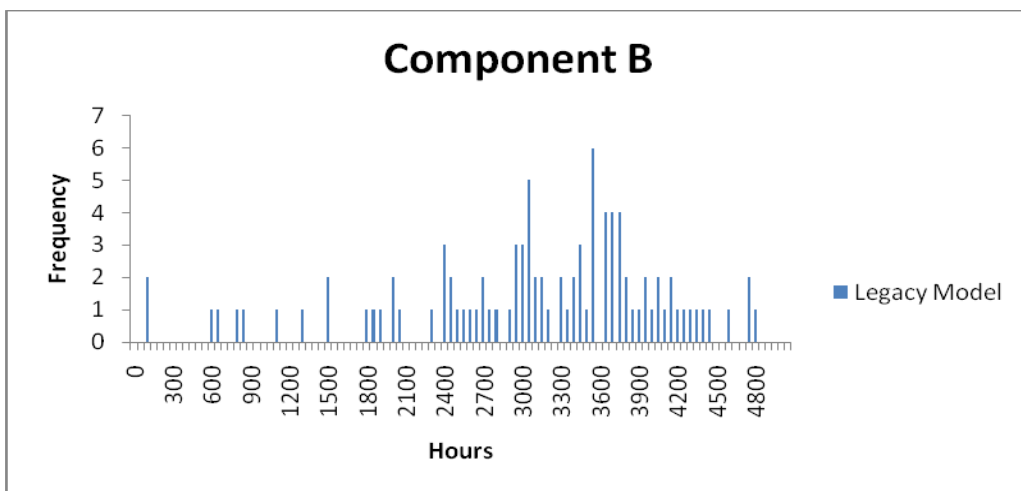
Figure 12. Legacy Model Component B--30-Year Lifecycle Average Time to Failure
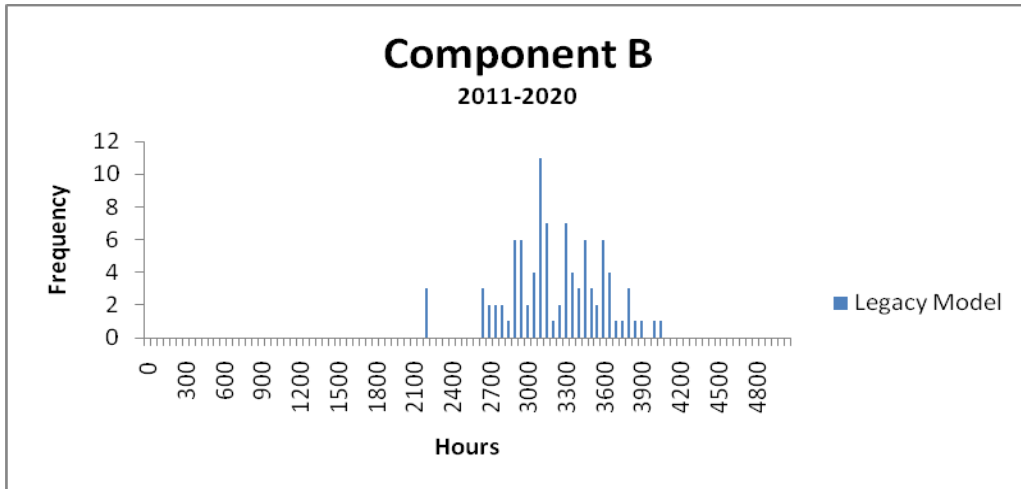
Figure 13. Legacy Model Component B--2011-2020 Average Time to Failure
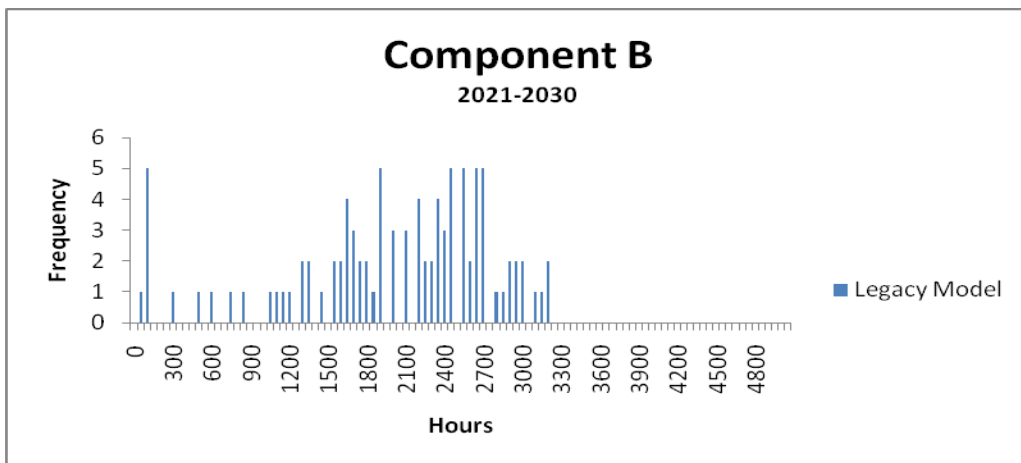
Figure 14. Legacy Model Component B--2021-2030 Average Time to Failure
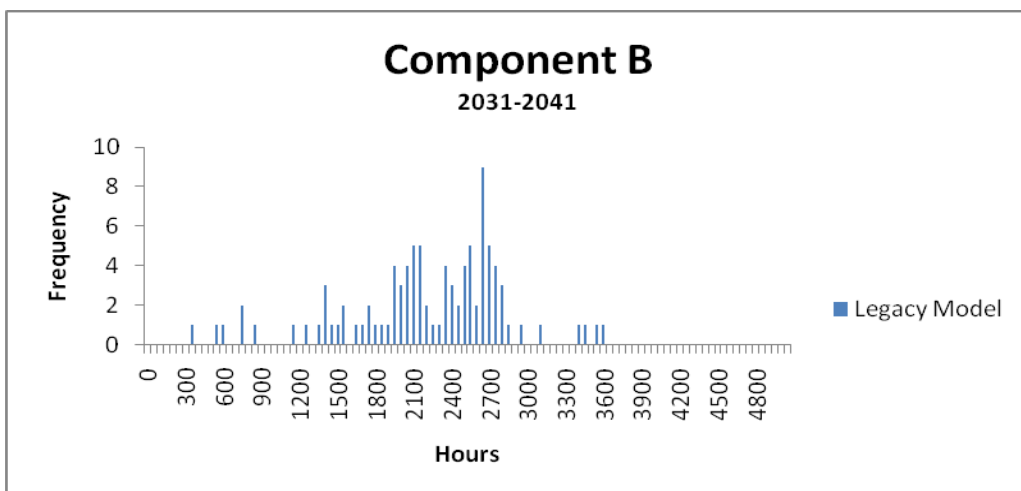
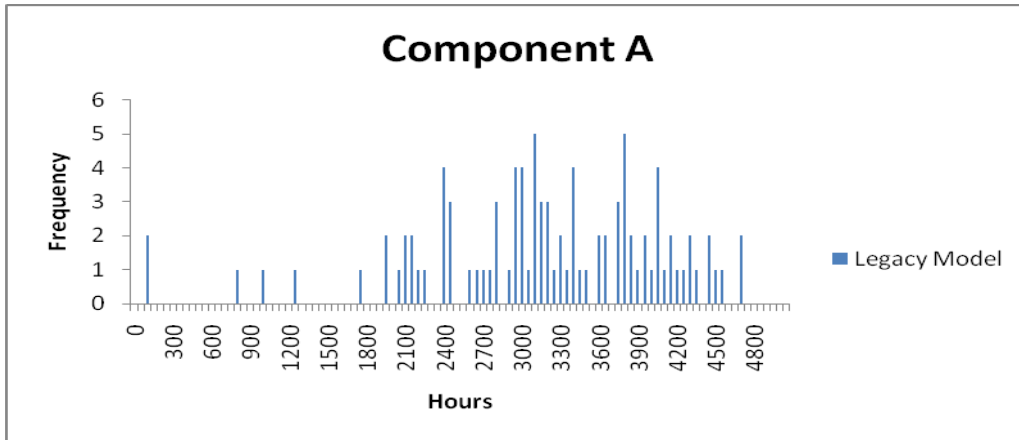**Figure 15. Legacy Model Component B--2031-2041 Average Time to Failure**

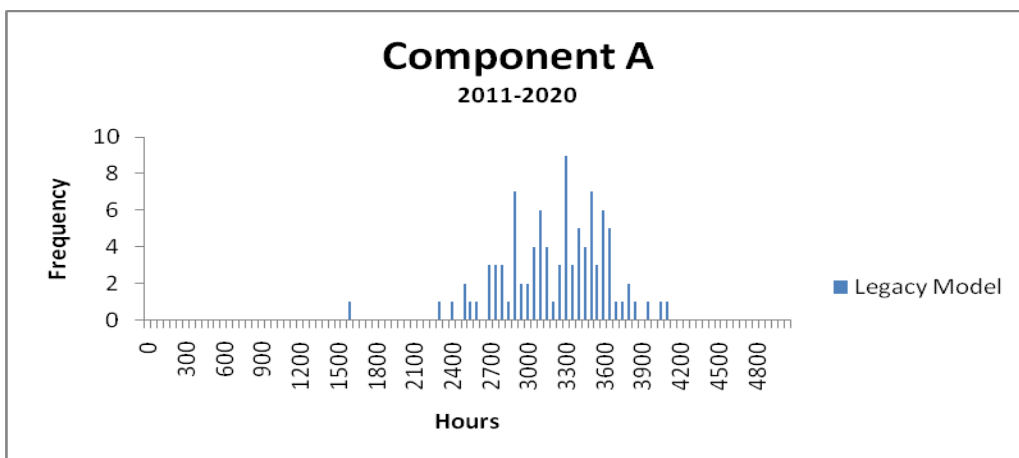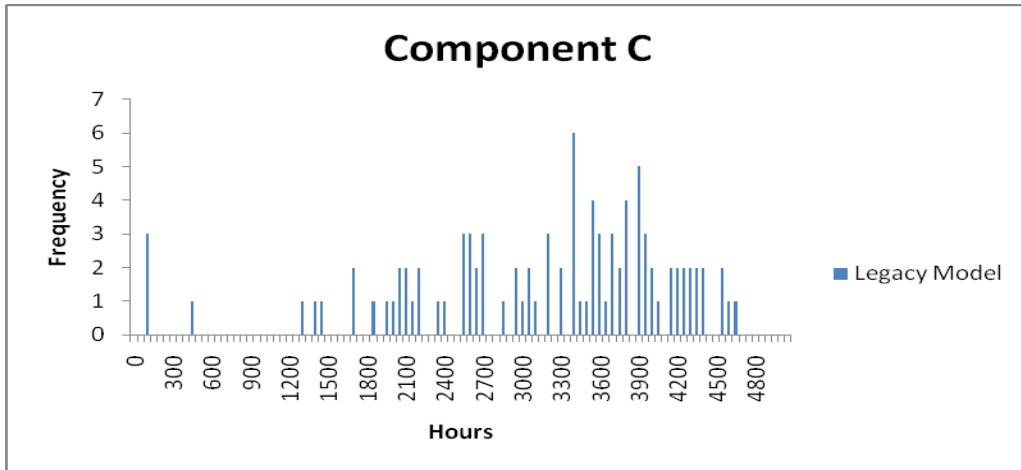**Figure 16. Legacy Model Component C--30-Year Lifecycle Average Time to Failure**
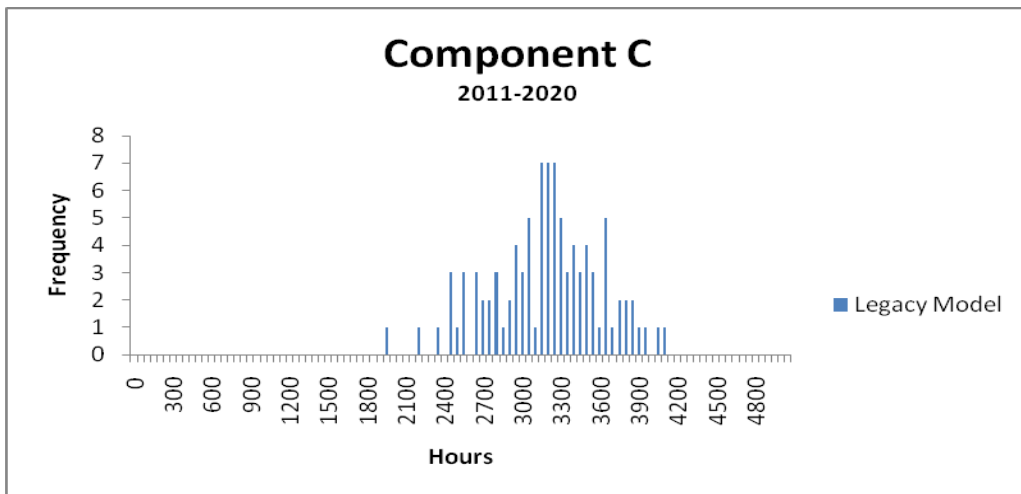
Figure 17. Legacy Model Component C--2011-2020 Average Time to Failure
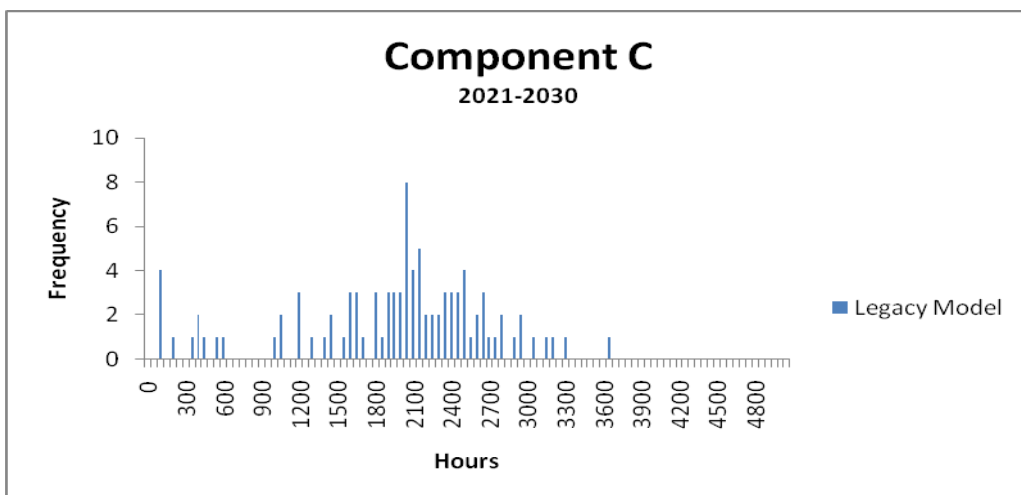
Figure 18. Legacy Model Component C--2021-2030 Average Time to Failure
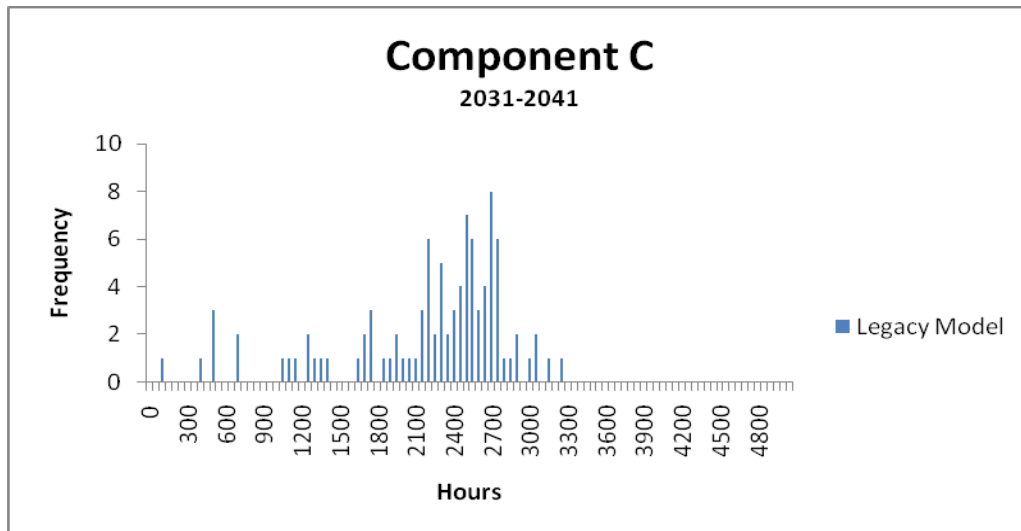
Figure 19. Legacy Model Component C--2031-2041 Average Time to Failure

The Programmed Upgrade Model results have a normal distribution for the Average Component Time to Failure as seen in the histogram charts for each component. The results from the model spans from 3,000 hours to 4,500 hours with a max height of 20 Time to Failures of 3,500 hours. The narrower range of the Programmed Upgrade Model results indicates that the variability remained nearly constant throughout the simulated test period negating the requirement to evaluate smaller time intervals.
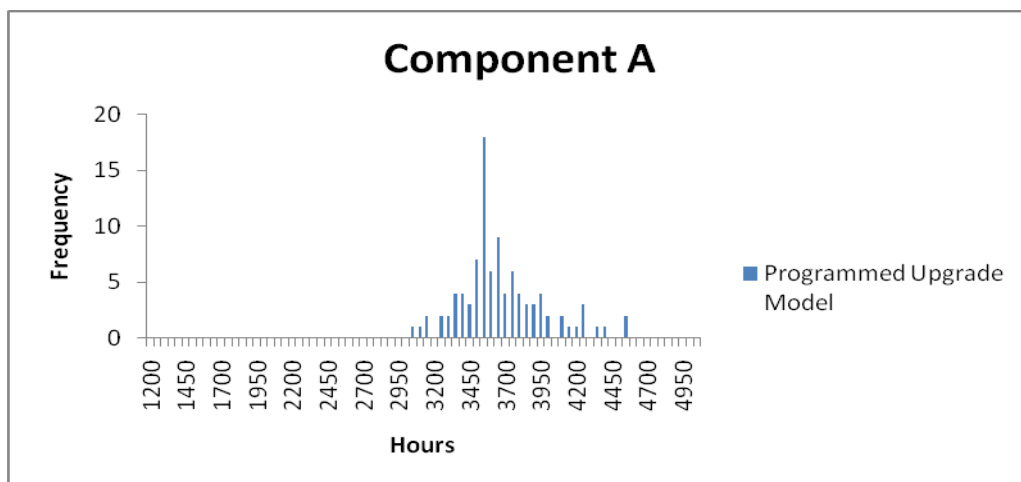
Figure 20. Programmed Upgrade Model Component A
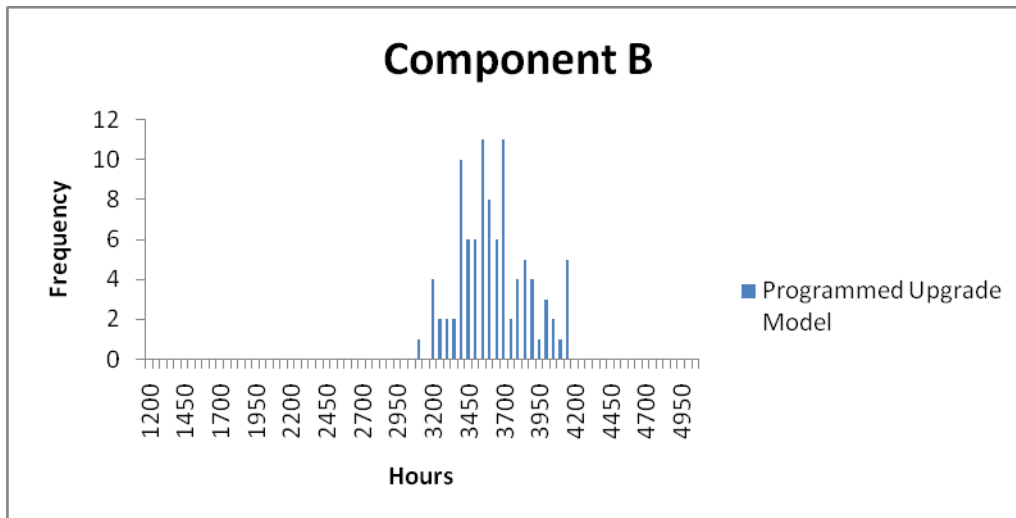
Figure 21. Programmed Upgrade Model Component B
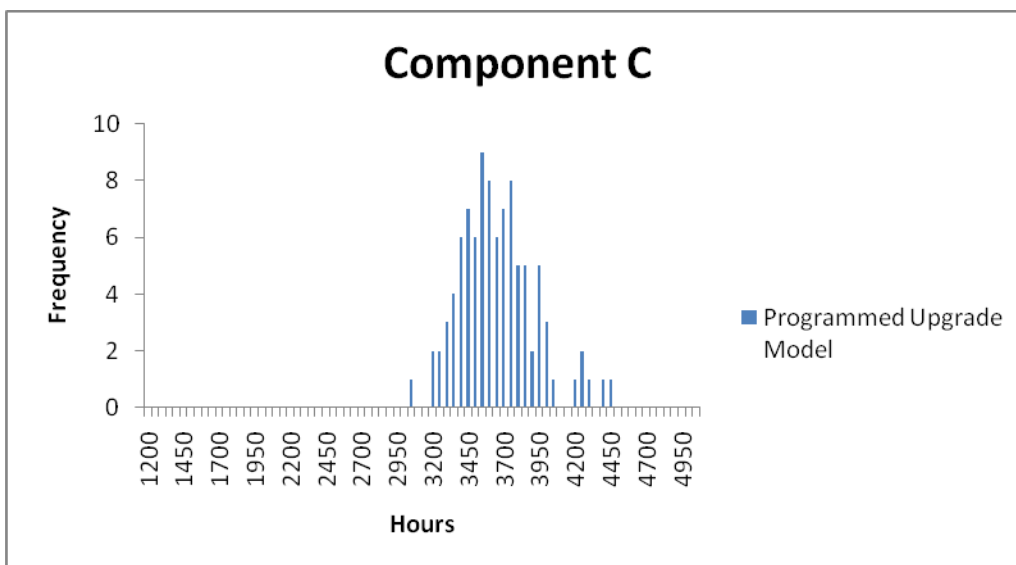
Figure 22. Programmed Upgrade Model Component C

As seen in the comparison charts below, the Programmed Upgrade Model Time to Failure average is higher than that of the Legacy Model, indicating higher utilization, reduced repair requirements, and possibly less cost over the lifecycle of the supported weapon system. While the full lifecycle time Legacy Model was found to be 12 percent lower than the Planned Upgrade Model, comparing the time interval model results shows this difference increases over time to nearly 50 percent.

Table 2. Component Average Time to Failure Comparison

	A		B		C	
Programmed Upgrade Model	**3648.29**		**3604.10**		**3633.19**	
Legacy Model Full Lifecycle	3133.54	↓14.11%	3057.81	↓15.16%	3110.85	↓14.38%
Legacy Model Interval 2011-2020	3196.62	↓12.38%	3193.67	↓11.39%	3158.74	↓13.06%
Legacy Model Interval 2021-2030	2162.87	↓40.72%	1955.95	↓45.73%	1885.53	↓48.10%
Legacy Model Interval 2031-2041	2141.38	↓41.30%	2177.40	↓39.59%	2169.42	↓40.29%

Initial comparison of the histograms indicates a reduction in variance for the Programmed Upgrade Model resulting in a more narrow distribution for average Time to Failure throughout the 30-year lifecycle of the supported weapon system. Next, the results from both models were compared using a two-tailed T-Test to determine the statistical significance for the difference. The T-tests results support Hypothesis 1, indicating a significant statistical difference between the Legacy Model and the Programmed Upgrade Model for all three avionics components with p-values of <.00001, for all three components.

Table 3. Average Time to Failure T-Test Comparison

	T-Test
Component A	0.000001529867571
Component B	0.000002457917378
Component C	0.000014258598852

Hypothesis 2 was tested using a Lifecycle Cost Model to compare the sustainment costs of the Legacy Model and Programmed Upgrade Model. During the 30-year simulation, annual sustainment costs for the Legacy Model steadily increased over time, while annual sustainment costs for the Programmed Upgrade Model experienced significantly lower growth over time.

The cost comparison models for the Legacy Strategy and the Programmed Upgrade Strategy are based on repair and acquisition costs for the F-16 AN/APG-68 radar memory cards (Steadman, 2000). Both models assumed an annual repair cost increase of 3 percent and evaluated components with initial acquisition costs of $8,000 for component A, $10,000 for component B, and $12,000 for component C. Initial repair costs were evaluated at $1,000 for component A, $2,000 for component B, and $3,000 for component C with programmed upgrade costs estimated at $2,000, $2,200, and $2,400. Annual and lifecycle costs were calculated as $S_o = \Sigma_{1-n} A_i + \Sigma_{1-n} C_i$ where S equals the equivalent annual sustainment cost occurring over n periods; A equals the acquisition cost of the replacement item; C equals the O&M repair costs during each period, i=1,2,…,n. The Legacy Model assumes no new system acquisition costs relying on repair processes to sustain the avionic components, whereas the Programmed Upgrade Model calculates a 5-year upgrade cost in the repair process and a 15-year programmed replacement cost. While the repair costs for the Legacy Model continue to increase by 3 percent annually, the Programmed Upgrade Model assumes that the introduction of new technology during the upgrade and replacement model will reset the repair costs at the original amount due to Moore's Law and the trend of new technology cost trends.

Figure 23. Legacy Model Component A Annual Sustainment Costs
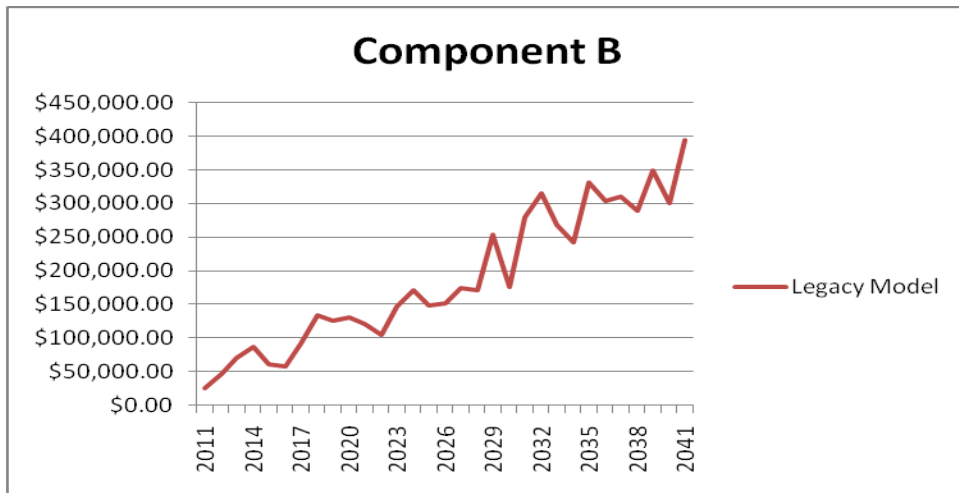
Figure 24. Legacy Model Component B Annual Sustainment Costs
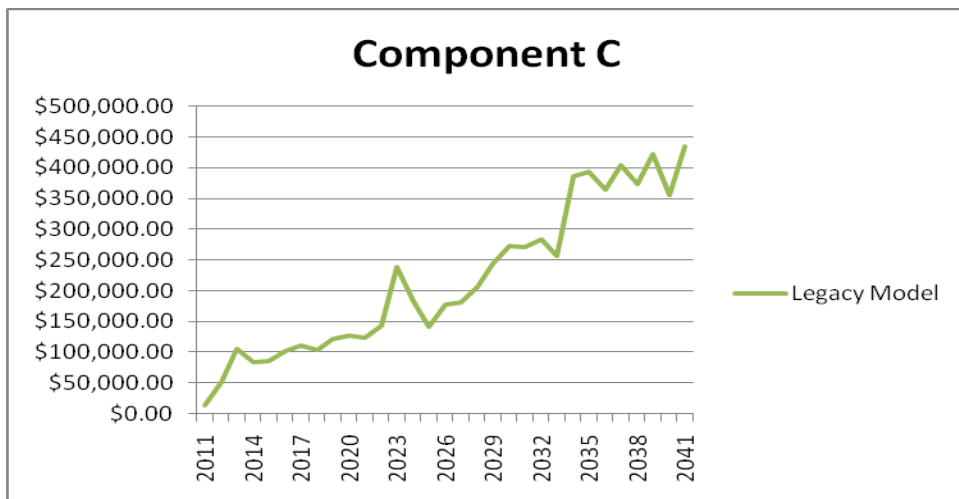
Figure 25. Legacy Model Component C Annual Sustainment Costs
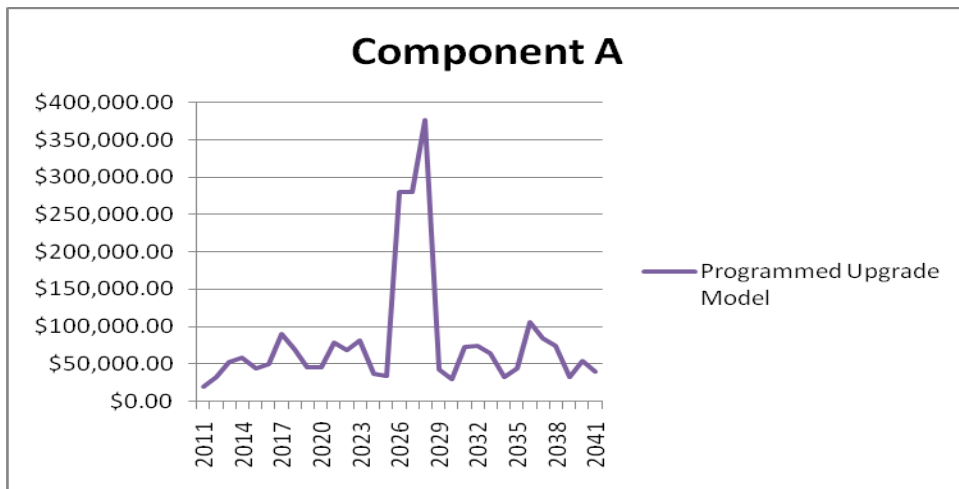
Figure 26. Programmed Upgrade Model Component A Annual Sustainment Costs
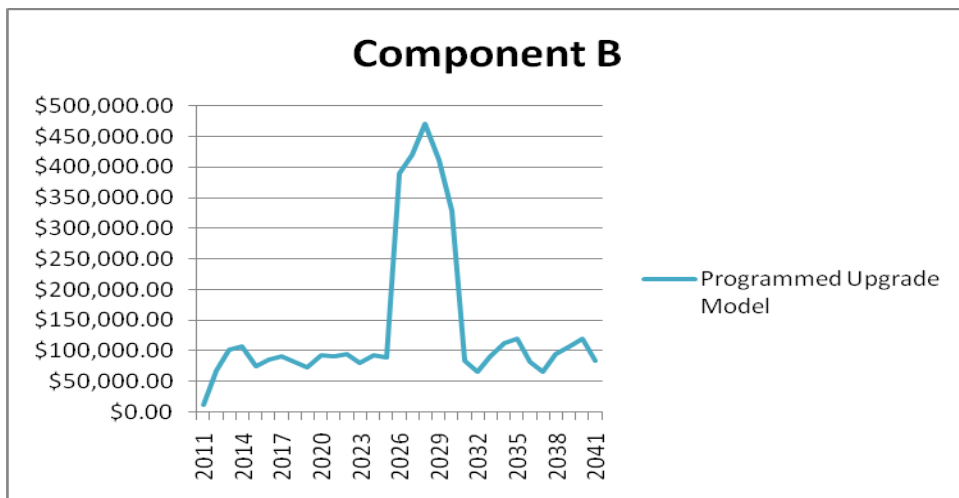
Figure 27. Programmed Upgrade Model Component B Annual Sustainment Costs
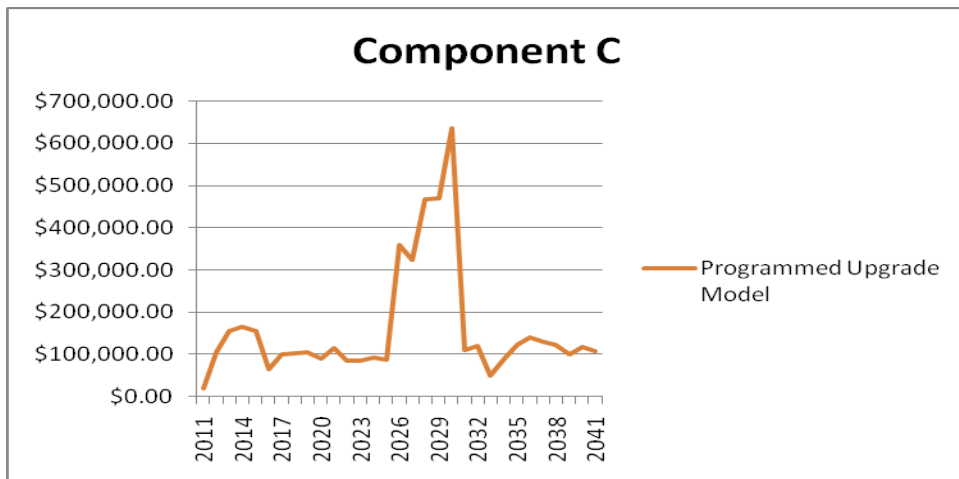
Figure 28. Programmed Upgrade Model Component C Annual Sustainment Costs

While the Programmed Upgrade Model identifies the predictable cost spikes during the scheduled upgrade point, the total lifecycle costs were 46 percent lower for component A, 26 percent lower for component B, and 26 percent lower for component C than the Legacy Model costs. An examination of the models during 10-year intervals revealed the Legacy Model component sustainment costs increased at nearly double the rate of the Programmed Upgrade Model.
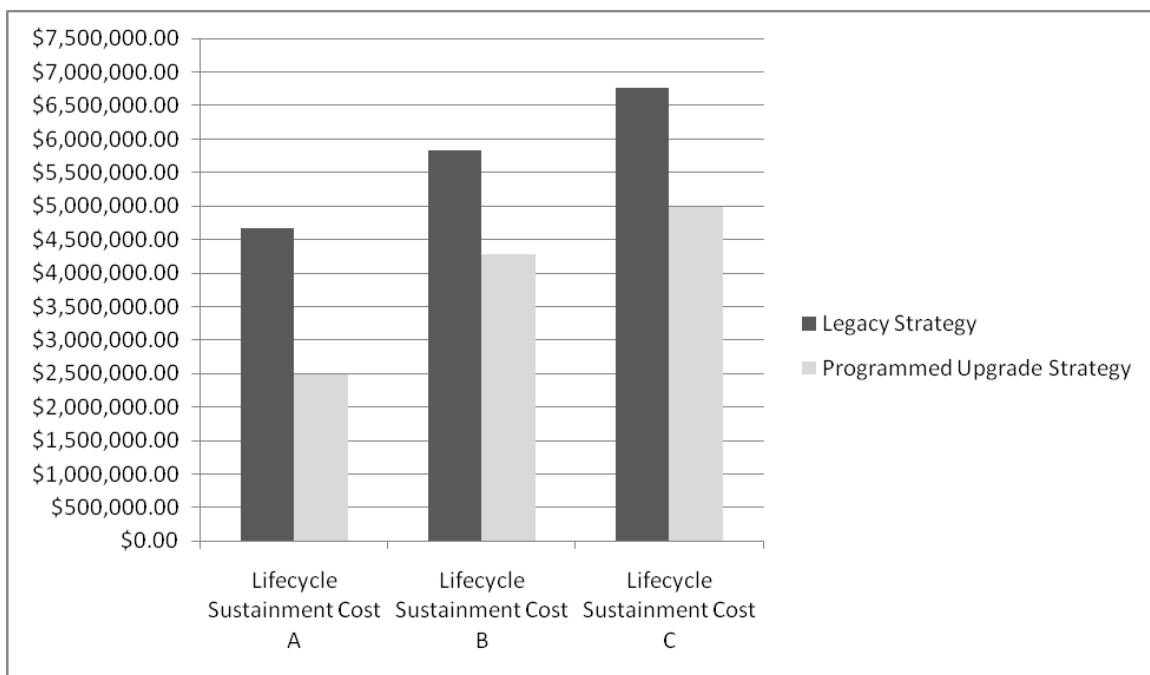
Figure 29. Lifecycle Sustainment Cost Comparison

Table 4. Legacy Model 10-Year Interval Sustainment Costs

Legacy Model	A	B	C
2011 Annual Cost	$15,000	$25,000	$14,000
2020 Annual Cost	$99,000	$131,000	$126,000
2030 Annual Cost	$119,000	$175,000	$272,000
2041 Annual Cost	$291,000	$175,000	$272,000
Full Lifecycle Cost	$4,670,000	$5,829,000	$6,759,000
Compared to Programmed Upgrade Model	↑ 87.39%	↑ 36.31%	↑ 35.58%

Table 5. Programmed Upgrade Model 10-Year Interval Sustainment Costs

Programmed Upgrade Model	A	B	C
2011 Annual Cost	$20,000	$11,000	$19,000
2020 Annual Cost	$46,000	$93,000	$89,000
2028 (Upgrade) Annual Cost	$376,000	$470,000	$636,000
2030 Annual Cost	$28,000	$66,000	$50,000
2041 Annual Cost	$39,000	$84,000	$117,000
Full Lifecycle Cost	**$2,492,000**	**$4,276,000**	**$4,985,000**
Compared to Legacy Model	↓ 46.63%	↓ 26.64%	↓ 26.24%

The annual sustainment cost for both models were compared using a two-tailed T-Test resulting in p-values <.1 for all three components, indicating a strong statistical significance. The Sustainment Cost Model analysis and T-test comparison support Hypothesis 2, indicating a lower total cost for all three components using the Programmed Upgrade Model.

Table 6. Annual Sustainment Costs T-Test Comparison

	T-Test
Component A	0.0012254
Component B	0.0852913
Component C	0.0933468

The results of this analysis are representative of the Time to Failure point and Annual Sustainment Cost of three avionics components across a fleet of 96 aircraft. In the operational Air Force, however, aircraft avionics systems are more complex integrating dozens or hundreds of electronic components (Hicks et al., 2003). These results from this study indicate that the Programmed Upgrade Strategy provides a valuable tool to reduce avionics sustainment costs. The next chapter addresses the research questions, provides a conclusion and offers further research areas.

V. Conclusions and Recommendations

Summary of Findings

The statistical test and cost analysis support the hypothesis that a strategy designed to upgrade and replace electronic avionic components can improve lifecycle reliability and result in significant annual and total lifecycle sustainment cost saving. The theoretical model in this study, when compared with data for the F-16 AN/APG68 radar system, closely resembles the actual repair, replacement, and annual O&M costs described by Bryan Steadman (2000). The F-16 fleet of 1,264 aircraft required over 300 memory cards annually to sustain the fleet. With a repair cost of $3,600 and a replacement cost of $14,000, the USAF spent $1.95M to annually support this single avionics component.

Table 7. Sustainment Cost Comparison

	Total Aircraft	Demands	Annual Sustainment Cost	Cost per Aircraft	Annual Savings	Annual Cost Adjusted to F-16 Fleet Size	Annual Savings Adjusted to F-16 Fleet Size
Legacy A	96	53	$119,238.41	$1,242.07		$1,569,972.42	
Legacy B	96	42	$147,138.52	$1,532.69		$1,937,323.89	
Legacy C	96	37	$102,817.46	$1,071.02		$1,353,763.16	
Upgrade A	96	28	$28,840.00	$300.42	$90,398.41	$379,726.67	$1,570,273.33
Upgrade B	96	36	$82,000.00	$854.17	$65,138.52	$1,079,666.67	$870,333.33
Upgrade C	96	43	$70,000.00	$729.17	$32,817.46	$921,666.67	$1,028,333.33
F-16	1264	300	$1,950,000.00	$1,542.72			

The Legacy Model results obtained in this study closely resembles the data for the F-16 radar system in year 20 of the model (2030) for Avionics A: $1,750 repair cost, $14,000 replacement cost and $119,000 annual sustainment; in year 13 (2023) for avionics component B: $1,700 repair cost, $14,000 replacement cost, and $147,000

annual sustainment cost; and in year 8 (2018) for avionics component C: with $1,700

repair cost, $14,700 replacement cost, and $102,000 annual sustainment cost. When

compared to the F-16 fleet the annual cost for avionic component B is within 1 percent of

the annual sustainment cost. When adjusted for a fleet size of 1,264, the Programmed

Upgrade Model suggests a savings opportunity of $870,000 annually, and a 30-year

lifecycle saving opportunity of nearly $108M. A comparison with the 648 aircraft in the

F-22 fleet suggests a lifetime savings of over $37M and annual saving of $929,000.

Implications of Findings

The implications of this study suggest an extensive opportunity to save billions of

dollars in avionics sustainment costs over the long lifecycle expectations of its military

aircraft. While the F-16, representing over 22 percent of the USAF aircraft inventory,

provide the greatest saving opportunities, expanding this sustainment across the USAF

inventory has the potential of saving nearly $12M annually, when used for one avionics

component per aircraft. Hicks et al. (2003) study explained that USAF aircraft avionics

systems utilize 53 to 475 electronic components, suggesting an annual saving opportunity

in of nearly $500M by adopting the Programmed Upgrade Strategy for avionics

sustainment.
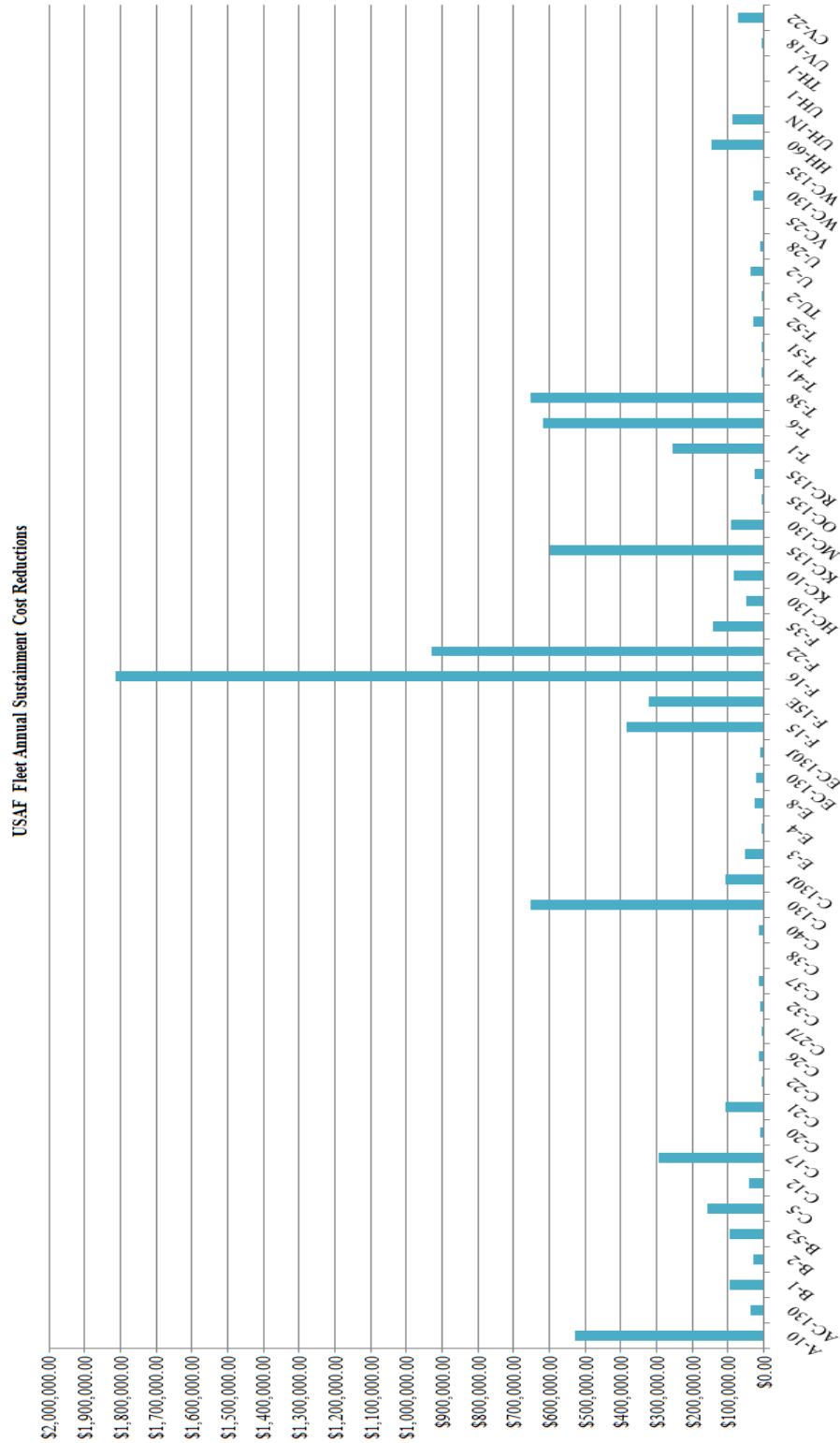
Figure 30. Estimated Annual Cost Reductions for One Component[5]

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[5] Estimated savings for one component per aircraft.
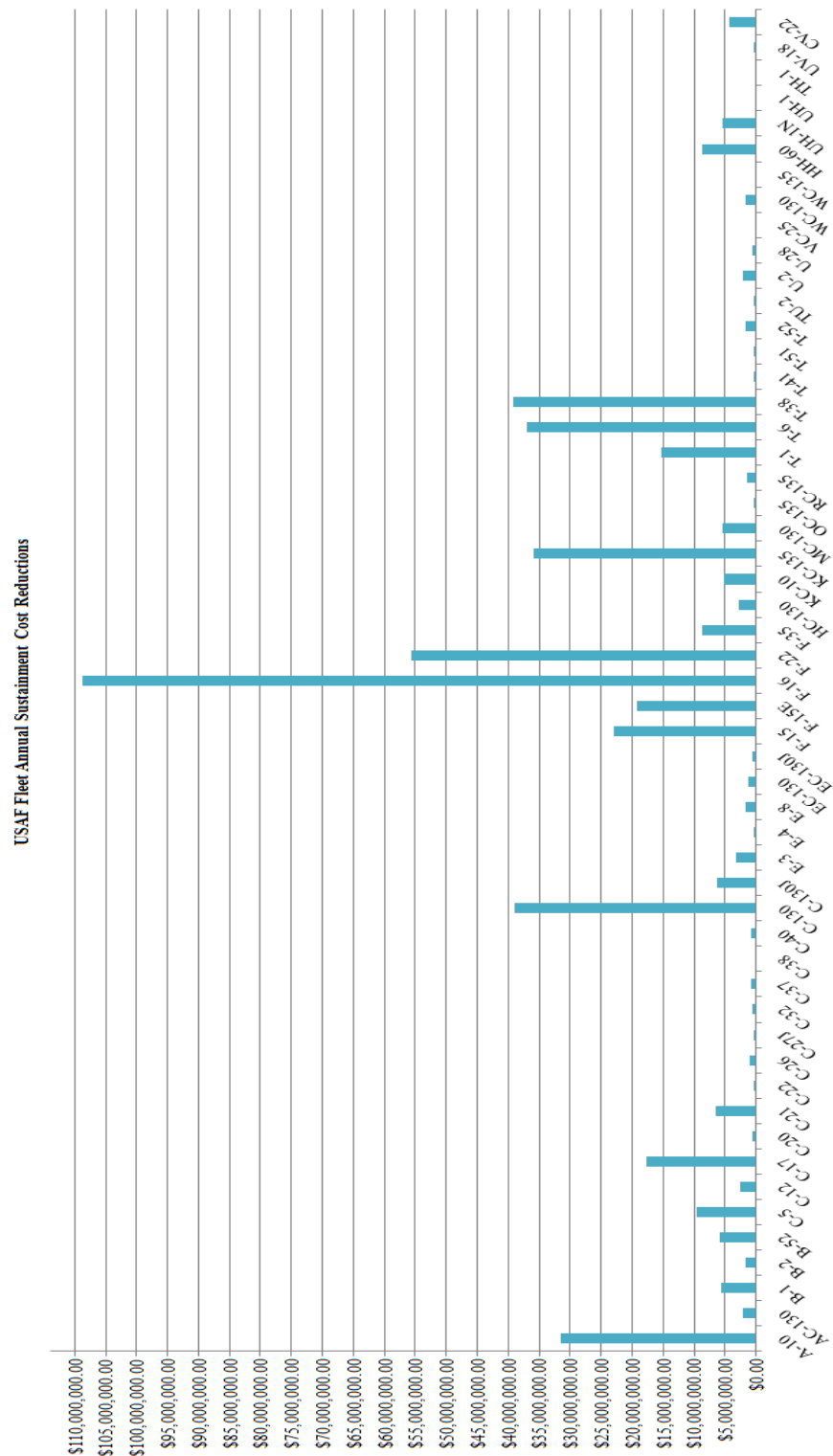
Figure 31. Estimated Annual Cost Reductions for Multiple Components[6]

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[6] Estimated savings for four avionics systems with fifteen components per aircraft.

Recommendations for Action and Further Research

Based on the research, there are several recommendations to improve the USAF sustainment strategy for electronic avionics. First, it is critical to maintain a complete Bill of Materials (BoM) for each weapon system in the USAF inventory. While this is difficult, without a thorough BoM, DMSMS management teams, SPOs, and weapon system managers will not have all of the information necessary to predict and/or prevent an obsolescence crisis. The BoM will provide key personnel the information required to identify potential problems early, identify possible courses of action, and implement economically feasible solutions.

While the BoM is a critical component to manage obsolescence threats, DMSMS prevention must begin before equipment is purchased and delivered. System requirements, to include the desired time-phased upgrades and replacement strategy must be coordinated with the design engineers and/or commercial contractor in the earliest phases of the acquisition process. A cross-functional process will allow engineers to design a system architecture that assumes a time-phased upgrade for components and software while at the same time allows the engineers to share the expected lifecycle time for specific components supporting the avionics system. Without this cross-functional collaboration, time-phased upgrades may not be possible due to limited architectural designs. Finally, contracts must be reviewed and revised to clearly define USAF and DoD requirements to support time-phased upgrades for electronic components and allow for economic incentives for contractors who provide systems that perform better than the contract objectives and penalties for systems that do not meet contract requirements.

There are many opportunities for additional research to test the model proposed in this study. First, detailed studies for specific weapon systems will provide the much more specific cost savings opportunities than the comparative framework proposed in this study. Key weapon systems that will benefit from further study of this model include the F-16 (22 percent in inventory), A-10 (6 percent of inventory), C-17 (3 percent of inventory), C-130 (8 percent of inventory), F-15 (8 percent of inventory), and the KC-135 (7 percent of inventory). Additional studies should be made to compare failure rates, optimal upgrade/replacement rates, and cost comparisons for specific avionic components such as display electronics, guidance and control systems, radar warning receivers, and flight indicators. The results of these studies will provide the framework to determine the USAF avionics sustainment strategy for the foreseeable future. Expanding the scope of this study to include US Navy, US Army, US Marines, and US Coast Guard fixed wing and rotary wing aircraft is a third opportunity for additional research.

In today's environment of rapid technology obsolescence, the DoD cannot afford to continue a strategy that reacts to DMSMS events. The DoD must continue to identify opportunities to reduce military spending. The current state of obsolescence management provides an attractive savings opportunity in both the short-run and long-run for the entire DoD. While this study has remained centered on avionics components, further opportunities are available for land based and sea based weapon systems, missile systems, satellites, and a myriad of mission systems in the Department of Energy, NASA, and other US agencies.

Acronym Glossary

AFIT	Air Force Institute of Technology
AFMC	Air Force Material Command
BOM	Mill of materials
COG	Component Obsolescence Group
COTS	Commercial-off-the-shelf
CPU	Central Processing Unit
DFAD	Design for adaptability
DMEA	Defense MicroElectronics Activity
DMS	Diminishing Manufacturing Sources
DMSMS	Diminishing Manufacturing Sources and Material Shortages
DoD	Department of Defense
DSCC	Defense Supply Center, Columbus
DSPO	Defense Standardization Program Office
DTM	Directive Type Memorandum
GAO	Government Accounting Office
GEM	Generalized Emulation of Microcircuits
GIDEP	Government-Industry Data Exchange Program
MIL-SPEC	Military Specifications
MIL-STD	Military-Standard
MoD	Ministry of Defense (United Kingdom)
NATO	North Atlantic Treaty Organization
O&M	Operations & Maintenance
RAM	Random Access Memory
USAF	United States Air Force

Appendix A. Model Results Tables

Table 8. Aircraft Age Chart at Start of Model

Aircraft	First Flight Date	AV A Age at test start	AV B Age at test start	AV C Age at test start
0001	1-Apr-07	2301.629998	2301.629998	2301.629998
0002	1-Apr-07	2306.561943	2306.561943	2306.561943
0003	2-Apr-07	2303.476191	2303.476191	2303.476191
0004	2-Apr-07	369.0676695	2311.127013	2311.127013
0005	3-Apr-07	2276.585078	2276.585078	2276.585078
0006	3-Apr-07	2296.234344	2296.234344	2296.234344
0007	1-Jul-07	2119.43059	2119.43059	2119.43059
0008	1-Jul-07	2165.331247	2165.331247	2165.331247
0009	2-Jul-07	2139.655313	2139.655313	2139.655313
0010	2-Jul-07	2115.313545	2115.313545	2115.313545
0011	3-Jul-07	2106.924077	2106.924077	2106.924077
0012	3-Jul-07	2104.732424	2104.732424	2104.732424
0013	1-Oct-07	2003.249696	2003.249696	2003.249696
0014	1-Oct-07	1987.429661	1987.429661	1987.429661
0015	2-Oct-07	1992.769561	1992.769561	1992.769561
0016	2-Oct-07	1980.250781	1980.250781	1980.250781
0017	3-Oct-07	1977.156759	1977.156759	1977.156759
0018	3-Oct-07	1940.589355	1940.589355	1940.589355
0019	1-Jan-08	1809.578667	1809.578667	1809.578667
0020	1-Jan-08	1797.58217	1797.58217	1797.58217
0021	2-Jan-08	1839.495181	1839.495181	1839.495181
0022	2-Jan-08	1821.423368	1821.423368	1821.423368
0023	3-Jan-08	1810.239572	1810.239572	1810.239572
0024	3-Jan-08	1870.279951	1870.279951	1870.279951
0025	1-Apr-08	1684.702725	1684.702725	1684.702725
0026	1-Apr-08	1637.228625	1637.228625	1637.228625
0027	2-Apr-08	1659.334599	1659.334599	1659.334599
0028	2-Apr-08	1681.722838	1681.722838	1681.722838
0029	3-Apr-08	1672.941809	1672.941809	1672.941809
0030	3-Apr-08	1698.03433	1698.03433	1698.03433
0031	1-Jul-08	1533.519047	1533.519047	1533.519047
0032	1-Jul-08	1527.125292	1527.125292	1527.125292
0033	2-Jul-08	1535.893699	1535.893699	1535.893699
0034	2-Jul-08	1539.358699	1539.358699	1539.358699
0035	3-Jul-08	1511.370879	1511.370879	1511.370879
0036	3-Jul-08	1538.952757	1538.952757	1538.952757

0037	1-Oct-08	1390.778045	1390.778045	1390.778045
0038	1-Oct-08	1389.316132	1389.316132	1389.316132
0039	2-Oct-08	1371.206957	1371.206957	1371.206957
0040	2-Oct-08	1381.406234	1381.406234	1381.406234
0041	3-Oct-08	1346.256536	1346.256536	1346.256536
0042	3-Oct-08	1356.350411	1356.350411	1356.350411
0043	1-Jan-09	1191.417408	1191.417408	1191.417408
0044	1-Jan-09	1215.831239	1215.831239	1215.831239
0045	2-Jan-09	1195.587263	1195.587263	1195.587263
0046	2-Jan-09	1205.512435	1205.512435	1205.512435
0047	3-Jan-09	1221.798358	1221.798358	1221.798358
0048	3-Jan-09	1227.482081	1227.482081	1227.482081
0049	1-Apr-09	1060.29878	1060.29878	1060.29878
0050	1-Apr-09	1085.264713	1085.264713	1085.264713
0051	2-Apr-09	1081.934463	1081.934463	1081.934463
0052	2-Apr-09	1070.926346	1070.926346	1070.926346
0053	3-Apr-09	1085.103162	1085.103162	1085.103162
0054	3-Apr-09	1064.036037	1064.036037	1064.036037
0055	1-Jul-09	925.0996993	925.0996993	925.0996993
0056	1-Jul-09	902.056571	902.056571	902.056571
0057	2-Jul-09	922.3875025	922.3875025	922.3875025
0058	2-Jul-09	922.7720461	922.7720461	922.7720461
0059	3-Jul-09	898.1984361	898.1984361	898.1984361
0060	3-Jul-09	924.4853519	924.4853519	924.4853519
0061	1-Oct-09	752.1577076	752.1577076	752.1577076
0062	1-Oct-09	746.3415134	746.3415134	746.3415134
0063	2-Oct-09	763.4500131	763.4500131	763.4500131
0064	2-Oct-09	789.4231017	789.4231017	789.4231017
0065	3-Oct-09	774.9299306	774.9299306	774.9299306
0066	3-Oct-09	778.8081975	778.8081975	778.8081975
0067	1-Jan-10	617.8635118	617.8635118	617.8635118
0068	1-Jan-10	594.8138344	594.8138344	594.8138344
0069	2-Jan-10	619.3559692	619.3559692	619.3559692
0070	2-Jan-10	598.5910909	598.5910909	598.5910909
0071	3-Jan-10	584.2331807	584.2331807	584.2331807
0072	3-Jan-10	590.9650784	590.9650784	590.9650784
0073	1-Apr-10	458.8883882	458.8883882	458.8883882
0074	1-Apr-10	458.6649175	458.6649175	458.6649175
0075	2-Apr-10	450.088915	450.088915	450.088915
0076	2-Apr-10	453.1321867	453.1321867	453.1321867
0077	3-Apr-10	461.6274188	461.6274188	461.6274188
0078	3-Apr-10	451.783087	451.783087	451.783087

0079	**1-Jul-10**	319.6384845	319.6384845	319.6384845
0080	**1-Jul-10**	321.9113558	321.9113558	321.9113558
0081	**2-Jul-10**	289.8755077	289.8755077	289.8755077
0082	**2-Jul-10**	308.7884689	308.7884689	308.7884689
0083	**3-Jul-10**	316.947348	316.947348	316.947348
0084	**3-Jul-10**	309.0104453	309.0104453	309.0104453
0085	**1-Oct-10**	149.2302477	149.2302477	149.2302477
0086	**1-Oct-10**	156.9497067	156.9497067	156.9497067
0087	**2-Oct-10**	155.1110931	155.1110931	155.1110931
0088	**2-Oct-10**	157.767936	157.767936	157.767936
0089	**3-Oct-10**	156.8395189	156.8395189	156.8395189
0090	**3-Oct-10**	138.3737218	138.3737218	138.3737218
0091	**1-Jan-11**	0	0	0
0092	**1-Jan-11**	0	0	0
0093	**2-Jan-11**	0	0	0
0094	**2-Jan-11**	0	0	0
0095	**3-Jan-11**	0	0	0
0096	**3-Jan-11**	0	0	0

Table 9. Legacy Model Avionics Demand Results

YEAR	Avionics A Demands	Avionics B Demands	Avionics C Demands
2011	15	21	10
2012	46	38	36
2013	52	48	63
2014	43	52	40
2015	38	30	39
2016	34	27	40
2017	55	42	44
2018	39	54	37
2019	28	46	38
2020	41	47	39
2021	54	38	35
2022	42	34	36
2023	36	42	59
2024	34	46	43
2025	44	38	29
2026	32	37	36
2027	43	39	35
2028	53	35	36
2029	36	51	42
2030	26	32	43
2031	53	48	39
2032	39	53	41
2033	38	43	35
2034	44	36	49
2035	37	48	47
2036	47	40	41
2037	44	39	43
2038	35	35	37
2039	37	39	41
2040	34	33	32
2041	36	40	37

Table 10. Programmed Upgrade Model Avionics Demands Results

YEAR	Avionics A Demands	Avionics B Demands	Avionics C Demands
2011	20	11	19
2012	32	33	34
2013	50	48	49
2014	53	49	50
2015	39	33	46
2016	25	39	27
2017	45	41	41
2018	35	37	43
2019	46	32	42
2020	44	40	35
2021	39	41	48
2022	34	43	35
2023	41	36	35
2024	37	41	37
2025	33	38	34
2026	35	39	30
2027	35	42	27
2028	47	47	39
2029	43	40	38
2030	28	31	50
2031	36	38	46
2032	37	30	50
2033	32	41	21
2034	32	50	36
2035	43	51	48
2036	53	37	58
2037	42	30	54
2038	37	43	51
2039	32	47	40
2040	53	51	46
2041	37	35	41

Appendix B. Additional Material

Blue Dart

First Name: <u>Kenneth</u>   Last Name: <u>Underwood</u>

Rank (Military, AD, etc.): <u>Major</u>   Designator # <u>AFIT/ILS/ENS/11-03</u>

Student's Involved in Research for Blue Dart: <u>Major Kenneth D. Underwood</u>

Position/Title: <u>AFIT IDE Masters Degree Student</u>

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School/Organization: <u>Air Force Institute of Technology</u>

Status: [x] Student   [ ] Faculty   [ ] Staff   [ ] Other

Optimal Media Outlet (optional): _____

Optimal Time of Publication (optional): _____

General Category / Classification:
[ ] core values   [ ] command   [ ] strategy
[ ] war on terror   [ ] culture & language   [ ] leadership & ethics
[ ] warfighting   [ ] international security   [ ] doctrine
[x] other (specify): <u>Logistics/Diminishing Manufacturing Sources and Material Shortages (DMSMS)</u>

Suggested Headline: <u>Minimizing DMSMS Risks</u>
Keywords: <u>technology insertion, sustainment technology process, obsolescence, DMSMS</u>

Blue Dart

   The Air Force faces increasingly difficult challenges to maintain and sustain its highly technical weapon systems, struggling against rapid technology advancement and diminishing lifecycle for electronic systems. The reduced lifecycle times have not only complicated sustainment, the lifecycles have diminished to the point that new military aircraft designs face challenges of obsolescence within the manufacturing cycle, and in some cases before manufacturing even begins. This research project explores Diminishing Manufacturing Sources and Material Shortages (DMSMS) and obsolescence cost associated with electronic avionic components. The overall research question asks how obsolescence management can be improved in the Air Force.

   This project utilizes two integrated models, the first, to determine electronic avionics demand requirements for a fleet of 96 aircraft over a 30-year period, and the second to evaluate sustainment cost over time for a) re-engineering strategy, b) lifetime buy strategy, and c) programmed redesign strategy. Statistical analysis and long-term cost comparison of these three strategies will provide a framework to evaluate specific weapon systems for future studies and to develop an attainable low-cost sustainment strategy.

   The views expressed in this article are those of the author and do not reflect the official policy or position of the United States Air Force, Department of Defense, or the US Government.

<div align="right">Apr 07</div>

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- Quantitative stu...
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- process changes
  - insertion
- Comparative and
- recommendation

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Vita
KENNETH D. UNDERWOOD, Maj, USAF

SKILLS

Team leadership; Complex problem solving; Public speaking; Teaching and training; Professional writing; Arena modeling software; JMP statistics software; Budgeting; Diminishing Manufacturing Sources and Material Supplied team certified; Contract negotiation experience; Air Terminal Operations/Management; Vehicle Fleet Management; Warehouse/Inventory Management; Special operations war-planning certified; Contingency planning; Natural disaster and crisis response team qualified; Combat survival training; Combat life saving skills; Elementary language skills in Arabic, French, Portuguese, Italian; Moderate language skills in Spanish; experienced world traveler Windows Office software.

EDUCATION

Graduate Study: University of Nevada, Las Vegas   2001-2009
        Major Field: History of the American West
        Minor Field: Latin American History
Dissertation: Mining Wars: Corporate Expansion and Labor Violence in the Western Desert
Doctorate conferred December 2009

Graduate Study: Air Force Institute of Technology   2010-2011
        Major Field: Supply Chain Management
Master of Science Degree in progress

Graduate Study: Texas A&M University, Kingsville   1995-1998
        Major Field: History and Political Science
Thesis: The Mexican Congress and Democratization in Mexico
Master of Science Degree conferred December 1998

Undergraduate Study: University of Southern California   1988-1992
        Major Field: International Relations
        Major Field: Political Science
Dual Bachelor of Arts Degree conferred May 1992

PROFESSIONAL MILITARY EDUCATION

AFIT Logistics Management/IDE   2011
Joint Special Operations War Planning Course   2009
Advanced Logistics Officer Readiness Course   2007
Air Command and Staff College   2006
Squadron Officer School   2003
Advanced Air Mobility Operations Course   1999

WORK EXPERIENCE

Assistant Professor of History, Norwich University   **Dec 2010-present**
-   Advises Master level graduate students during thesis development and completion

C/J4 Director of Logistics, ISAF Special Operations HQ   **Sep 2009-Dec 2009**
Kabul, Afghanistan
- J/4 Directed Logistics for Special Operations Forces for the International Security Assistance Force, Afghanistan supporting 5 Special Operations Coordination Elements and 13 Special Operations Task Forces from 12 contributing nations
- Guaranteed fuel, secure communications, and maintenance support enabled SOF units to conduct 80 missions, capturing over 100 insurgents, 3000 Kg of illegal drugs, and several large weapons caches
- Oversaw 100 combat convoy missions, personally leading 45 missions throughout Kabul and between Kabul and Bagram Airbase

ADVON Team Commander/A-4Director of Logistics Exercise Jackal Stone   May-June 2009
Split, Croatia
- Led 10 person team to construct tent city for 265 special operations personnel; Joint Air Operations Center established within 48 hours of arrival establishing secure communications for exercise location
- Coordinated logistics support for 9-nation multi-national exercise with 3 different fixed-wing aircraft types and 5 different rotary-wing aircraft models and 700 personnel

Director of Logistics, 352 Special Operations Group, RAF Mildenhall   Jul 2007-May 2010
United Kingdom
- Led 14 person flight responsible for all logistics support to an overseas 739 person special operations group
- Led airfield survey teams in 5 Eastern European nations for multi-national counter-terrorism exercises
- Directed SOF logistics in 28 nations, 12K flight hours/2500 sorties/22K tons of cargo/21K personnel deployed to and returned home from contingency operations
- Drove 135 person/4 MC-130/Special Operations Command Europe logistics response to Georgian conflict; Command & Control node in place in less than 12 hours
- Authored logistics plan for first-ever special operations CV-22 Osprey overseas deployment; 3 C-17 aircraft, 96 passengers, 78 tons of cargo and 4 CV-22s deployed to Africa with no delays: CV-22 proved mission ready for special operations taskings
- Formulated the deployment plan delivering special operations airpower to Chad within 36 hours, evacuating 140 civilians and the United States Ambassador during 2008 rebel uprising

Director of Operations 380 Logistics Readiness Sq, Al Dhafra Air Base   Jun 2006-May 2007
United Arab Emirates
- Second-in-command of 126 deployed Airmen comprised of 7 different logistics specialties; directed daily operations for receipt and delivery of over 425K gallons of aviation and ground fuel
- Led Air Terminal Operations support for over 100 transient aircraft per month
- Maintained a 574 vehicle fleet valued at $31M; achieving 95 percent vehicle in-commission rate, highest in deployed theater

Assistant Professor, Department of History   **Jun 2003-June 2006**
United States Air Force Academy, CO
- Managed facilities, equipment, reports, decorations, safety and security programs, and $20K budget for 31 faculty and staff.
- Assistant Professor for History and Humanities courses and Advisor in charge of 129 Foreign Area Studies interdisciplinary major.
- Exercise Evaluation Team member and Logistics advisor for 10th Air Base Wing

   University Courses Taught
   History 101 – World History
   Foreign Area Studies 425 – Model Organization of American States
   Humanities 499 – Central Asian Literature and Culture
   Humanities 430 – The Holocaust

Flight Commander, Distribution, Nellis AFB   **Nov 2002-May 2003**
Las Vegas, Nevada
- Led 146 personnel in 5 aircraft parts stores, 9 warehouses, and the command's largest distribution facility supporting 8 aircraft maintenance units and 30 repair shops
- Processed 3000 passengers, 600 tons cargo for wartime requirements in Afghanistan and Iraq
- Managed 59K items valued at $402M with 99.99 percent accuracy for F-22 and Predator UAV

Commander, Logistics Readiness Flight, Bagram Airfield,   **Jul 2002-Nov 2002**
Bagram, Afghanistan
- Coordinated movement of 392 personnel and 322 tons of cargo for Special Operations missions throughout Afghanistan
- Led team to Dushanbe, Tajikistan to resolve vehicle maintenance issue and prepare cargo for shipment, solving 3-month problem
- Coordinated distribution of 50K lbs of school supplies for Afghan children from Canadian Children in Crisis relief agency
- Led the safe/rapid movement of 27,247 tons of cargo, 30,600 passengers on 4,227 airlift missions in black-out conditions utilizing Night Vision Goggles with no accidents/incidents

Flight Commander Vehicle Operations, Nellis AFB   **Feb 2001-Jul 2002**
Las Vegas, Nevada
- Led 79 personnel managing the AF's largest operational vehicle fleet: 2063 valued at $117M, supporting over 39,000 transportation requests annually
- Officer in charge of cargo deployment operations, prepared and shipped 66 RQS helicopters, 126 tons of cargo in 5 C-17 aircraft less than 96 hours from notification
- Led transportation squadron recovery effort after aircraft mishap; team vehicles, cranes, flatbed trucks ready ahead of planned timelines

Flight Commander Combat Readiness, Incirlik AFB,   **Apr 2000-Feb2001**
Incirlik,Turkey
- Provided Logistics support of Operation Northern Watch forces, NATO units, and associated units throughout Turkey
- Resource Advisor responsible for squadron budget of $1.6M providing vehicle maintenance for 692 vehicles, and international shipping operations
- Expedited the movement of over 6,000 critical aircraft parts ensuring the accuracy of customs documents and challenging discrepancies; 25 discrepancies noted saving over $60K

Flight Commander Vehicle Operations, Prince Sultan AFB   **Jun 1999-Nov 1999**
Kingdom of Saudi Arabia
- Managed 950 vehicles in contingency environment, maintaining over 97 percent in-commission rate
- Designed shuttle bus route and safely moved over 160,000 passengers in 90 days on 24/7 shuttle bus
- Project Manager for the United States Central Command and United Stated Transportation Command co-sponsored Containerized Ammunition Distribution System exercise; developed shipping contract for line haul vehicles to move exchange than 500 containers of retrograde ammunition across 300 miles of desert from the base to the sea-port

Flight Commander Combat Readiness, McConnell AFB   **Dec 1997-Jan 1999**
Wichita, Kansas
- Formulated, planned, developed, and reviewed requirements, plans, and studies in support of peacetime and wartime operations
- Planned and executed 22 Air Refueling Wings rapid deployment of over 507 tons of cargo, 1,141 passengers on 109 global reach missions

HONORS AND AWARDS

Meritorious Service Medal	May 2010
Defense Meritorious Service Medal	Dec 2009
AFSOC Field Grade Officer of the Year	Dec 2008
World History Instructor of the Year	May 2006
Department of History, USAFA	
Meritorious Service Medal	May 2006
Inspector General Outstanding Contributor	Dec 2005
USAFA Operational Readiness Inspection	
Company Grade Officer of the Year	2003/2004/2005
Department of History, USAFA	
Bronze Star Medal	Jun 2003
455 AEW CGO Award Bagram, Afghanistan	Nov 2002
99 ABW CGO Award Nellis AFB	Oct 2001
363 AEW CGO Award Saudi Arabia	Aug 1999
Inducted Phi Alpha Theta Honor Society	Apr 1996

PUBLICATIONS

Book Review
"Review *The Last Flight of Bomber 31*" *Checkpoints*, December 2004.

COMMUNITY SERVICE

- Red Cross volunteer, fund raising drives, crisis volunteer, and lifesaving skills course instructor
- Member of community speakers program PAYBAC; speaking with at risk youth to promote continued education

REPORT DOCUMENTATION PAGE

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13. SUPPLEMENTARY NOTES

14. ABSTRACT

   The Air Force faces increasingly difficult challenges to maintain and sustain its highly technical weapon systems, struggling against rapid technology advancement and diminishing lifecycle for electronic systems. The reduced lifecycle times have not only complicated sustainment, the lifecycles have diminished to the point that new military aircraft designs face challenges of obsolescence within the manufacturing cycle, and in some cases before manufacturing even begins. This research project explores Diminishing Manufacturing Sources and Material Shortages (DMSMS) and obsolescence cost associated with electronic avionic components. The overall research question asks how obsolescence management can be improved in the Air Force.

   This project utilizes two integrated models, the first, to determine electronic avionics demand requirements for a fleet of 96 aircraft over a 30-year period, and the second, to evaluate sustainment cost over time for a) re-engineering strategy, b) lifetime buy strategy, and c) programmed redesign strategy. Statistical analysis and long-term cost comparison of these three strategies will provide a framework to evaluate specific weapon systems for future studies and to develop an attainable low-cost sustainment strategy.

15. SUBJECT TERMS:
 Diminishing Manufacturing Sources and Material Supplies, DMSMS, Avionics, Obsolescence, Lifecycle, Sustainment, Modeli*ng*

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a. REPORT U	b. ABSTRACT U	c. THIS PAGE U	UU	92	19b. TELEPHONE NUMBER *(Include area code)* (937) 255-6565, ext 4653; e-mail: Jeffrey.Ogden@afit.edu

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